US012342332B2

(12) **United States Patent**
Xin et al.

(10) **Patent No.: US 12,342,332 B2**
(45) **Date of Patent: Jun. 24, 2025**

(54) **MULTI-LINK RESTRICTED TWT**

(71) Applicants: **SONY GROUP CORPORATION**, Tokyo (JP); **SONY CORPORATION OF AMERICA**, New York, NY (US)

(72) Inventors: **Liangxiao Xin**, Santa Clara, CA (US); **Mohamed Abouelseoud**, Burlingame, CA (US); **Li-Hsiang Sun**, San Jose, CA (US); **Qing Xia**, San Jose, CA (US)

(73) Assignees: **SONY GROUP CORPORATION**, Tokyo (JP); **SONY CORPORATION OF AMERICA**, New York, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 356 days.

(21) Appl. No.: **18/049,285**

(22) Filed: **Oct. 24, 2022**

(65) **Prior Publication Data**

US 2023/0139168 A1 May 4, 2023

Related U.S. Application Data

(60) Provisional application No. 63/263,340, filed on Nov. 1, 2021.

(51) **Int. Cl.**
H04W 72/12 (2023.01)
H04W 52/02 (2009.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04W 72/12*** (2013.01); ***H04W 52/0216*** (2013.01); ***H04W 74/0816*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC . H04W 72/12; H04W 76/15; H04W 52/0216; H04W 74/0816; H04W 74/0833; H04W 74/0866; H04W 84/12
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2021/0289512 A1 9/2021 Hu
2021/0329500 A1 10/2021 Cariou
2021/0360646 A1 11/2021 Chu

FOREIGN PATENT DOCUMENTS

JP 2024508532 8/2022
JP 2024532781 A 9/2024
TW 20211015 A1 3/2021

OTHER PUBLICATIONS

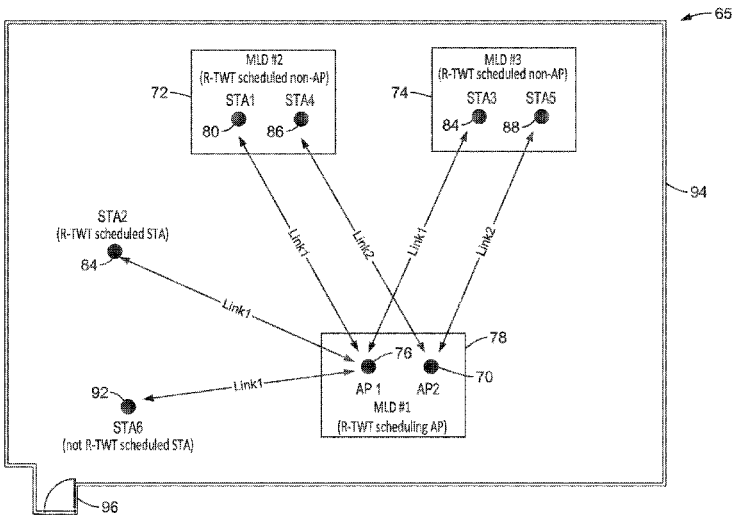
Jason Yuchen Guo (Huawei Technologies Co Ltd): "CR-for-TXOP-Termination-of-NSTR-MLD", IEEE Draft; 11-21-1416-01-00BE-CR-FOR-TXOP-TERMINATION-Of-NSTR-MLD, IEEE-SA Mentor, Piscataway, NJ USAvol. 802.11 EHT; 802.llbe, No. 1 Oct. 12, 2021 (Oct. 12, 2021), pp. 1-4, XP068185366.
(Continued)

Primary Examiner — Gbemileke J Onamuti
(74) *Attorney, Agent, or Firm* — O'BANION & RITCHEY LLP; John P. O'Banion

(57) **ABSTRACT**

A wireless protocol CSMA/CA and scheduling SPs of a R-TWT for RTA frame exchange. In addition to link level scheduling, R-TWTs can be scheduled from an MLD level. An R-TWT scheduling MLD is configured to schedule a Multi-Link (ML) R-TWT with SP scheduled on multiple links. These ML R-TWTs can be one or more SL R-TWTs, and a ML R-TWT can be an independent R-TWT from the SL R-TWT. The R-TWT scheduling MLD can: (a) assign a unique ML level R-TWT ID to identify a ML R-TWT, and if a ML R-TWT consists of SL R-TWTs each SL R-TWT is assigned to a unique link level R-TWT ID to identify it on its link; and (b) complete ML R-TWT signaling on one link for the ML R-TWT management on multiple links.

24 Claims, 33 Drawing Sheets



(51) **Int. Cl.**

H04W 74/08	(2024.01)
H04W 74/0816	(2024.01)
H04W 74/0833	(2024.01)
H04W 76/15	(2018.01)
H04W 84/12	(2009.01)

(52) **U.S. Cl.**

CPC ... ***H04W 74/0833*** (2013.01); ***H04W 74/0866*** (2013.01); ***H04W 76/15*** (2018.02); *H04W 84/12* (2013.01)

(56) **References Cited**

OTHER PUBLICATIONS

802 11 Working Group of the LAN/MAN Standards Committee of the IEEE Computer Society: "Draft Standard for Information technology-Tele-communications and information exchange between systems Local and metropolitan area networks—Specific requirements ?? Part 11: Wireless LAN Medium Access Control ? (MAC) and Physical Layer (PHY) Specifications ?? Amendment 8: Enhancements for extre", IEEE Draft; Draft ,P802.11BE_D1.2_REDLINE_COMPARED_TO_DI.1, IEEE-Sa, Piscataway, NJ USA.

Chunyu Hu et al., "Protected TWT Enhancement for Latency Sensitive Traffic", IEEE 802.11-20/1046r5, Aug. 2020.

Liwen Chu et al., "Low Latency Support", IEEE 802.11-20/1058r0, Sep. 2, 2020.

Zhou Lan et al., "MLO Typical Usage Cases and Sub-Feature Prioritization", Broadcom Inc., IEEE 802.11-20/292r0, Jan. 2020.

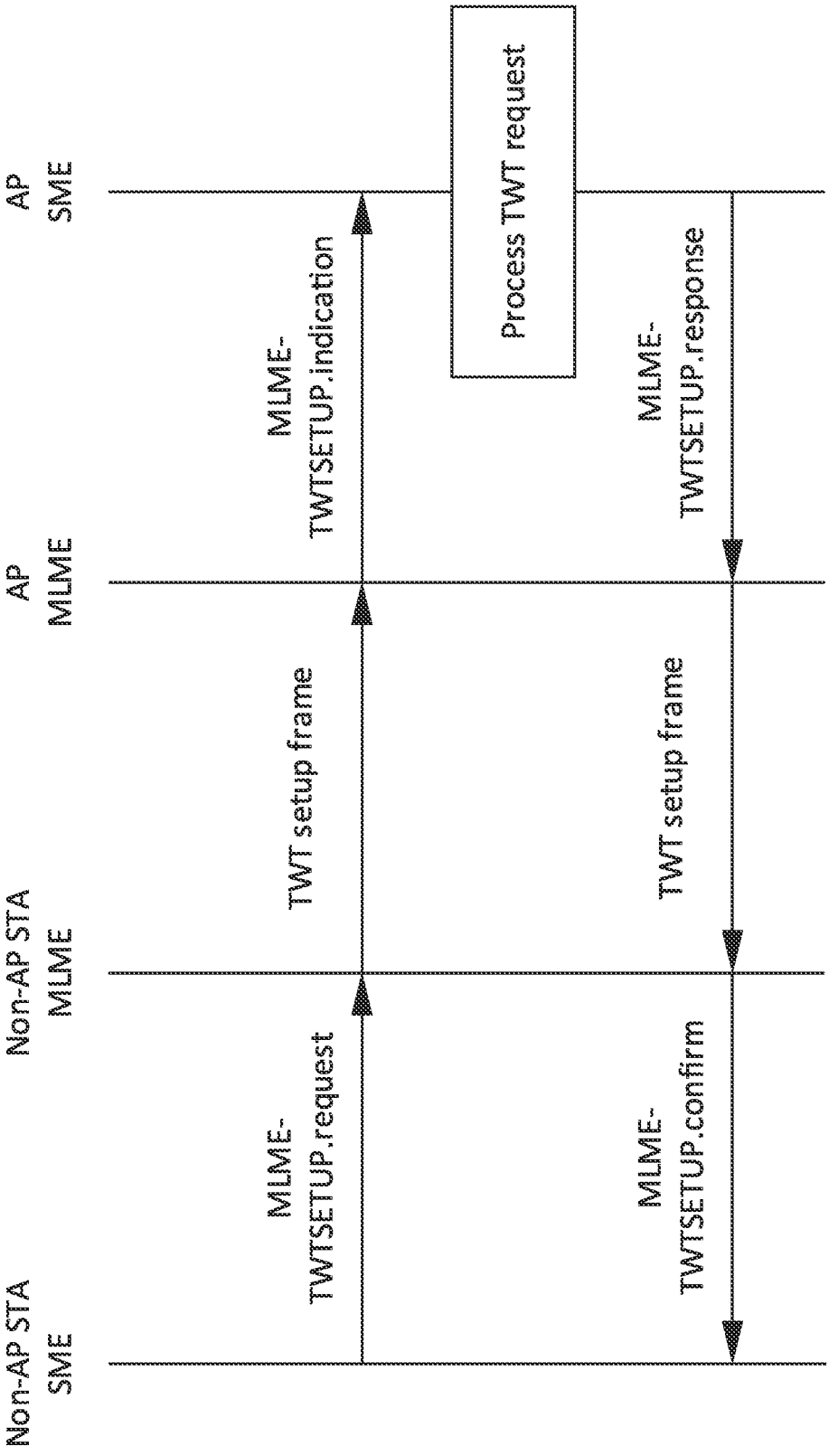


FIG. 1
(Prior Art)

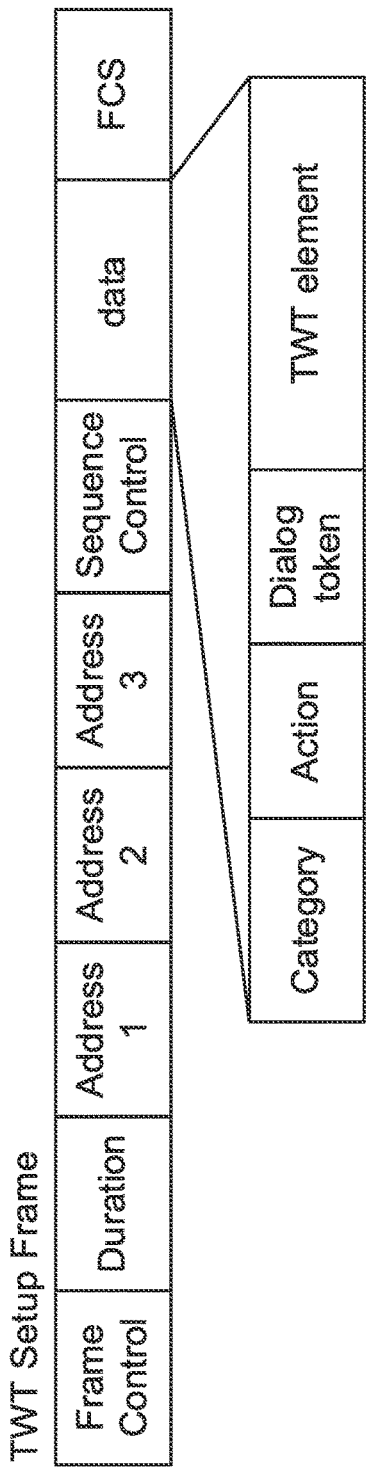


FIG. 2
(Prior Art)

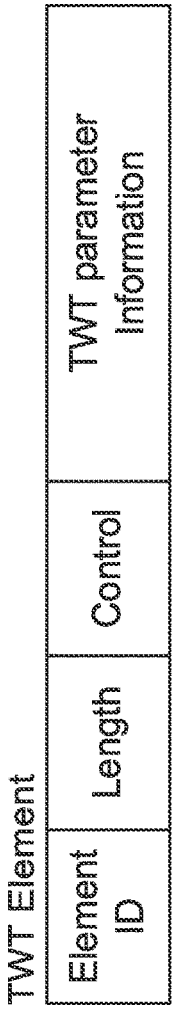


FIG. 3
(Prior Art)

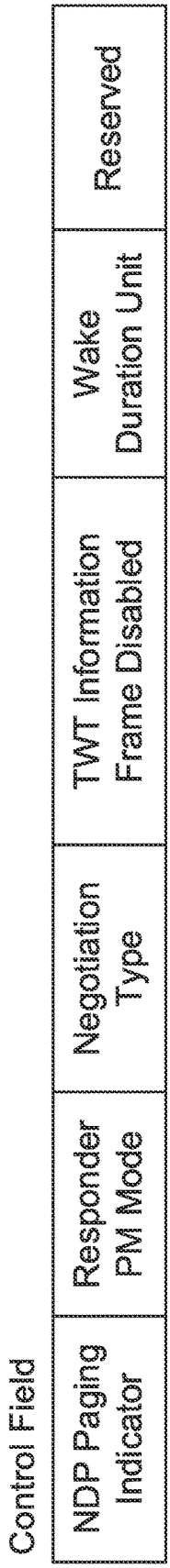


FIG. 4
(Prior Art)

Broadcast TWT Info Field (type 2 or 3)

Request Type	Target Wake Time	Nominal Minimum TWT Wake Duration	TWT Wake Interval Mantissa	Broadcast TWT Info	Restricted TWT Traffic Info (optional)

FIG. 5
(Prior Art)

Request Type Field

TWT Request	TWT Setup Command	Trigger	Last Broadcast Parameter Set	Flow Type	Broadcast TWT Recommendation	TWT Wake Interval Exponent	Reserved

FIG. 6
(Prior Art)

Broadcast TWT Info Field

Restricted TWT Traffic Info Present	Reserved	Broadcast TWT ID	Broadcast TWT persistence

FIG. 7
(Prior Art)

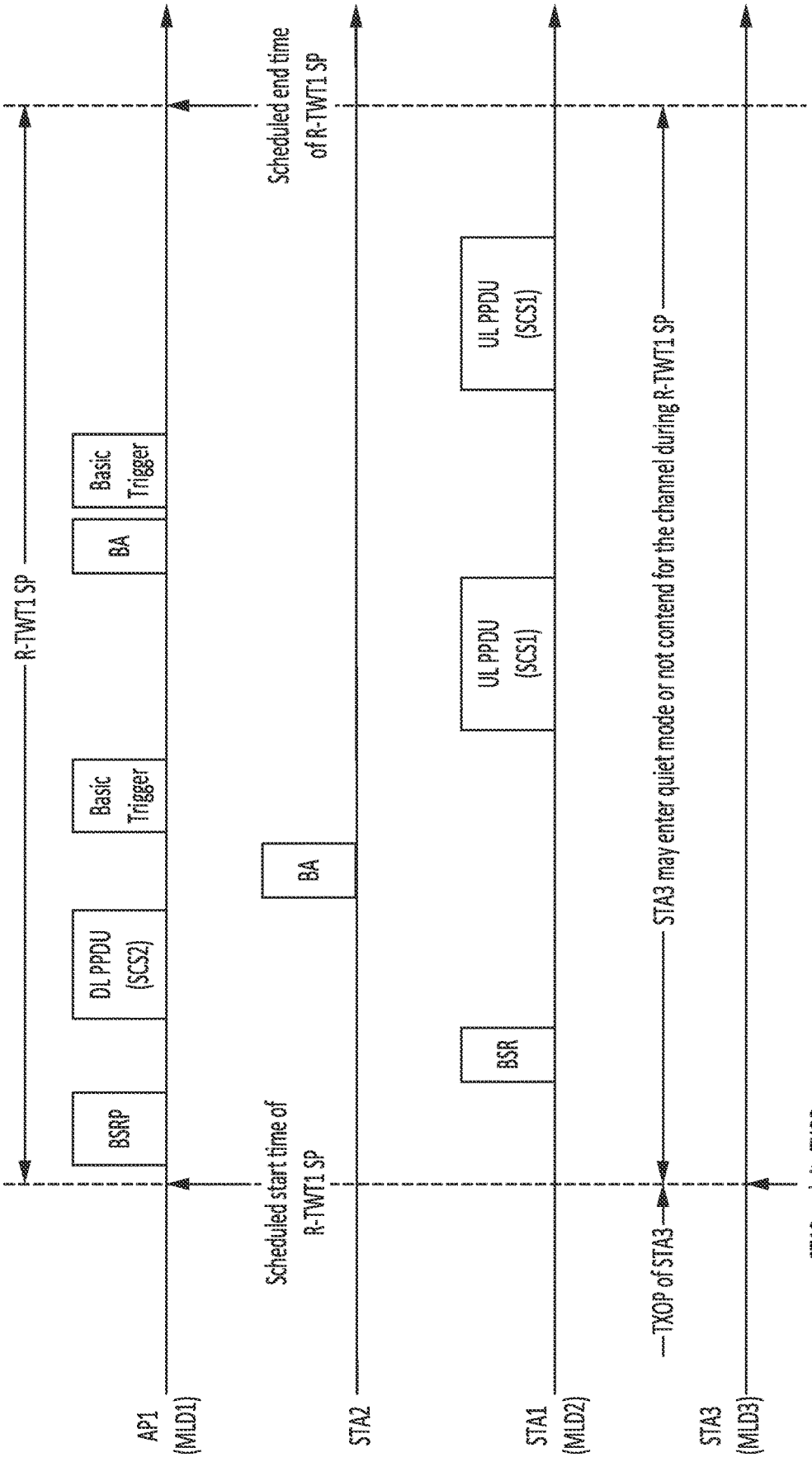


FIG. 8
(Prior Art)

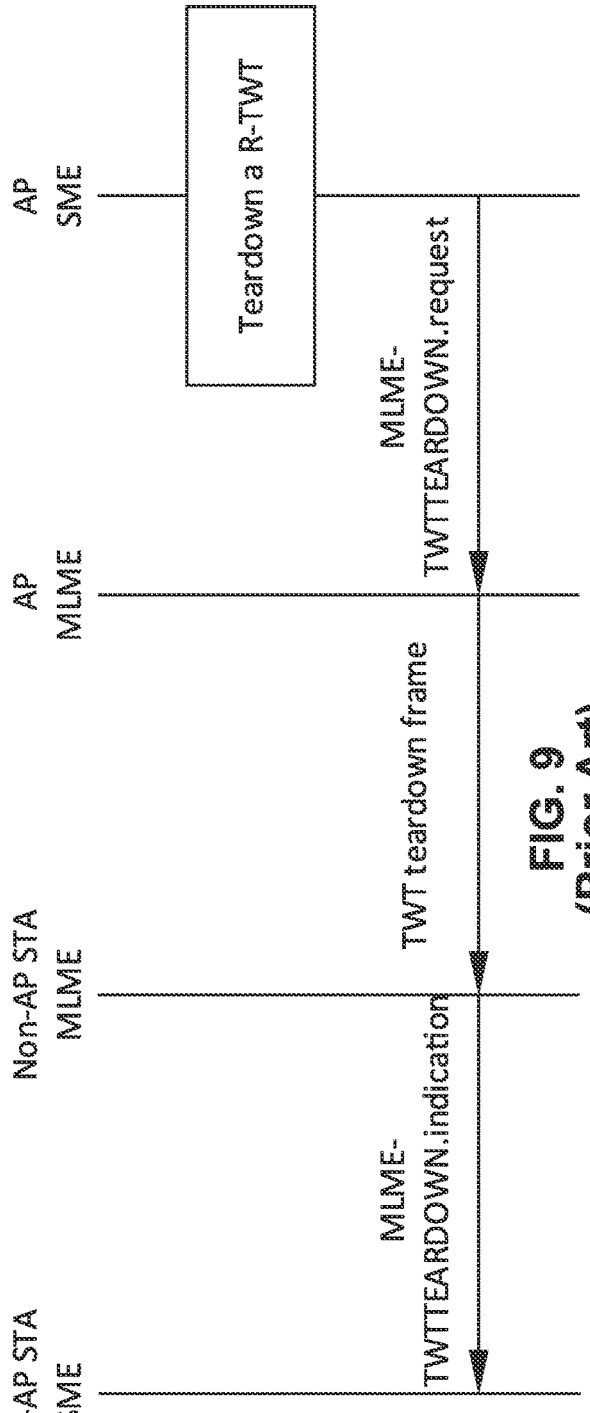


FIG. 9
(Prior Art)

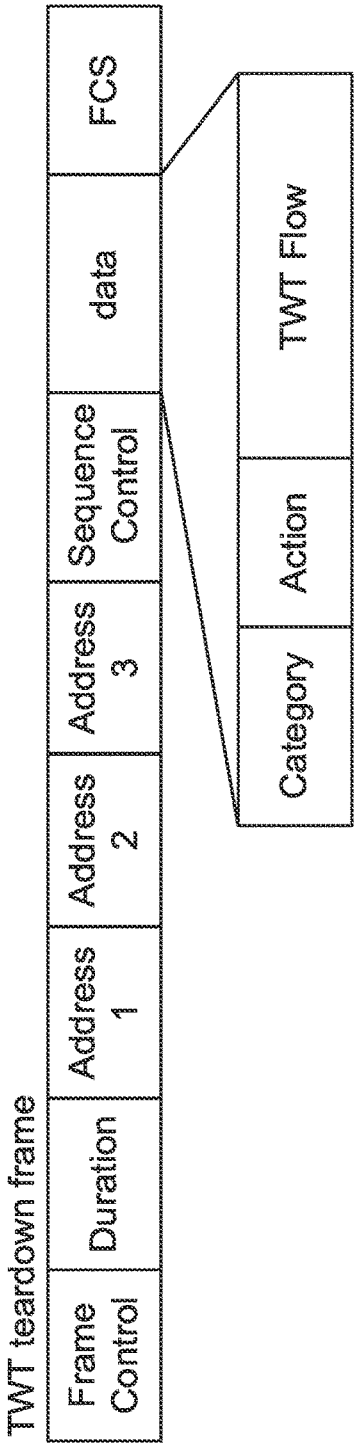


FIG. 10
(Prior Art)

TWT Flow Field (type = 0 or 1)

TWT Flow Identifier	Reserved	Negotiation Type	Teardown All TWT

FIG. 11
(Prior Art)

TWT Flow Field (type = 2)

Reserved	Negotiation Type	Reserved

FIG. 12
(Prior Art)

TWT Flow Field (type = 3)

Broadcast TWT ID	Negotiation Type	Teardown All TWT

FIG. 13
(Prior Art)

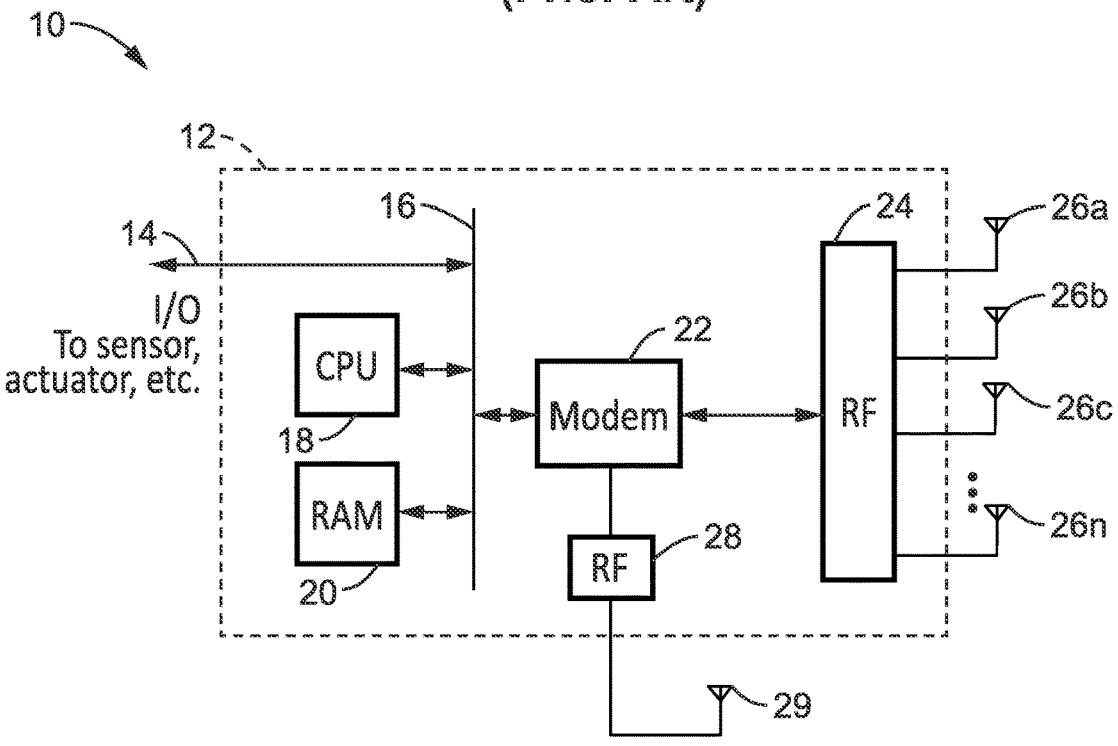


FIG. 14

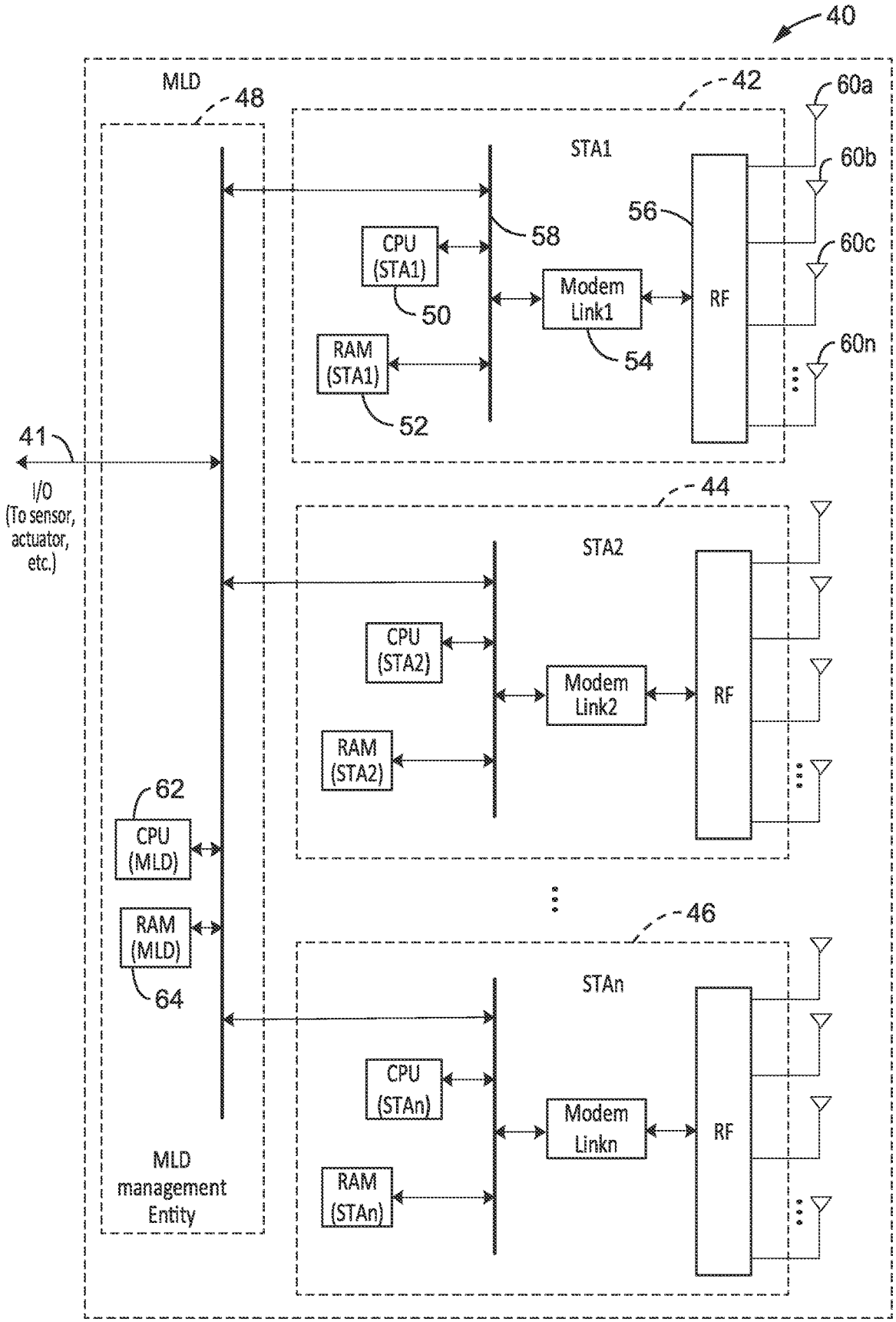

40
MLD
48
42
60a
STA1
60b
56
58
CPU
(STA1)
Modem
Link1
RF
60c
50
RAM
(STA1)
54
60n
52
41
I/O
(To sensor,
actuator,
etc.)
44
STA2
CPU
(STA2)
Modem
Link2
RF
RAM
(STA2)
62
CPU
(MLD)
RAM
(MLD)
64
46
STAn
CPU
(STAn)
Modem
Linkn
RF
RAM
(STAn)
MLD
management
Entity

FIG. 15

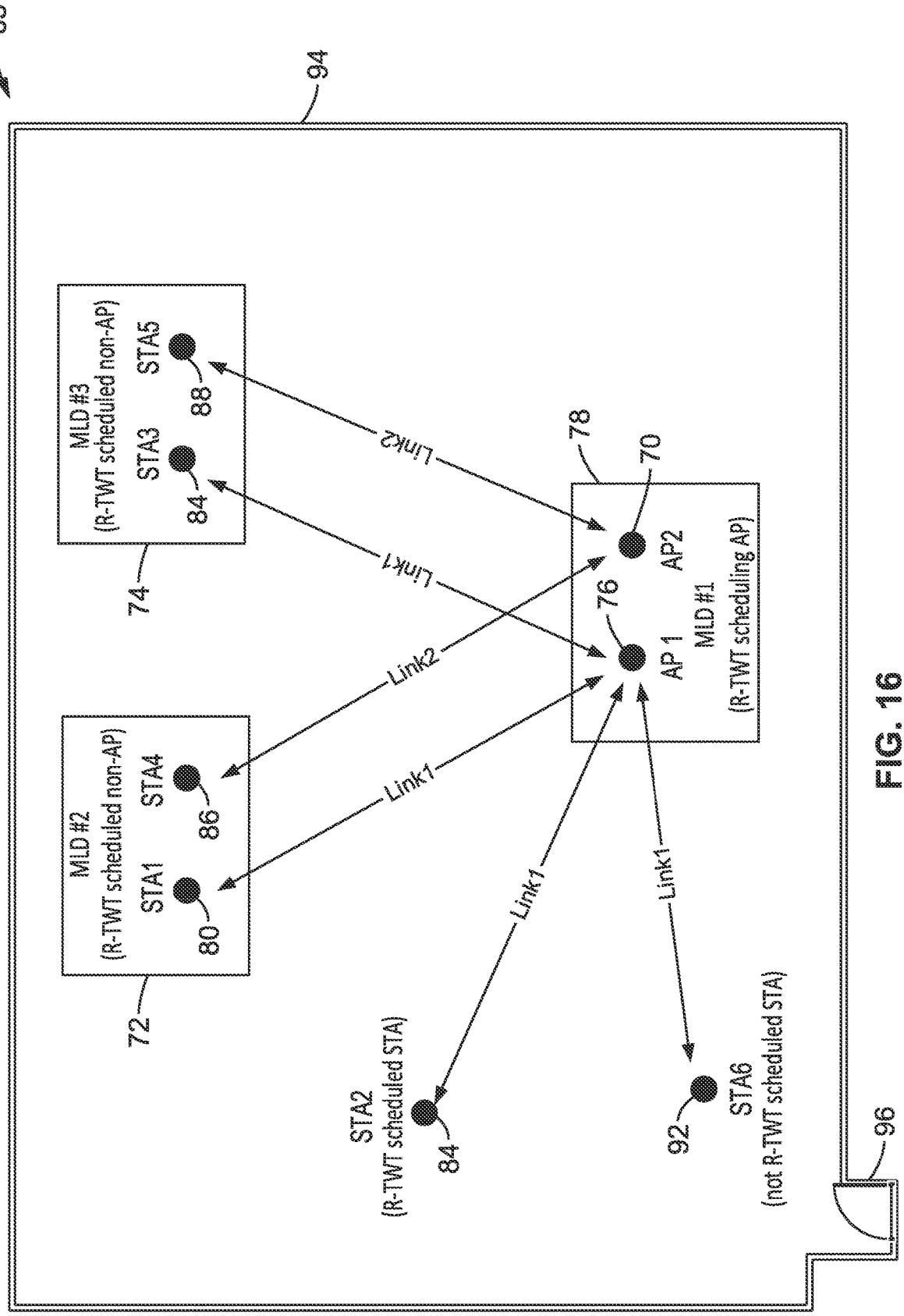

65
94
MLD #3
(R-TWT scheduled non-AP)
STA3
STA5
84
88
74
Link2
Link1
78
70
AP2
76
AP 1
MLD #1
(R-TWT scheduling AP)
Link2
Link1
MLD #2
(R-TWT scheduled non-AP)
STA1
STA4
80
86
72
Link1
Link1
STA2
(R-TWT scheduled STA)
84
92
STA6
(not R-TWT scheduled STA)
96

FIG. 16

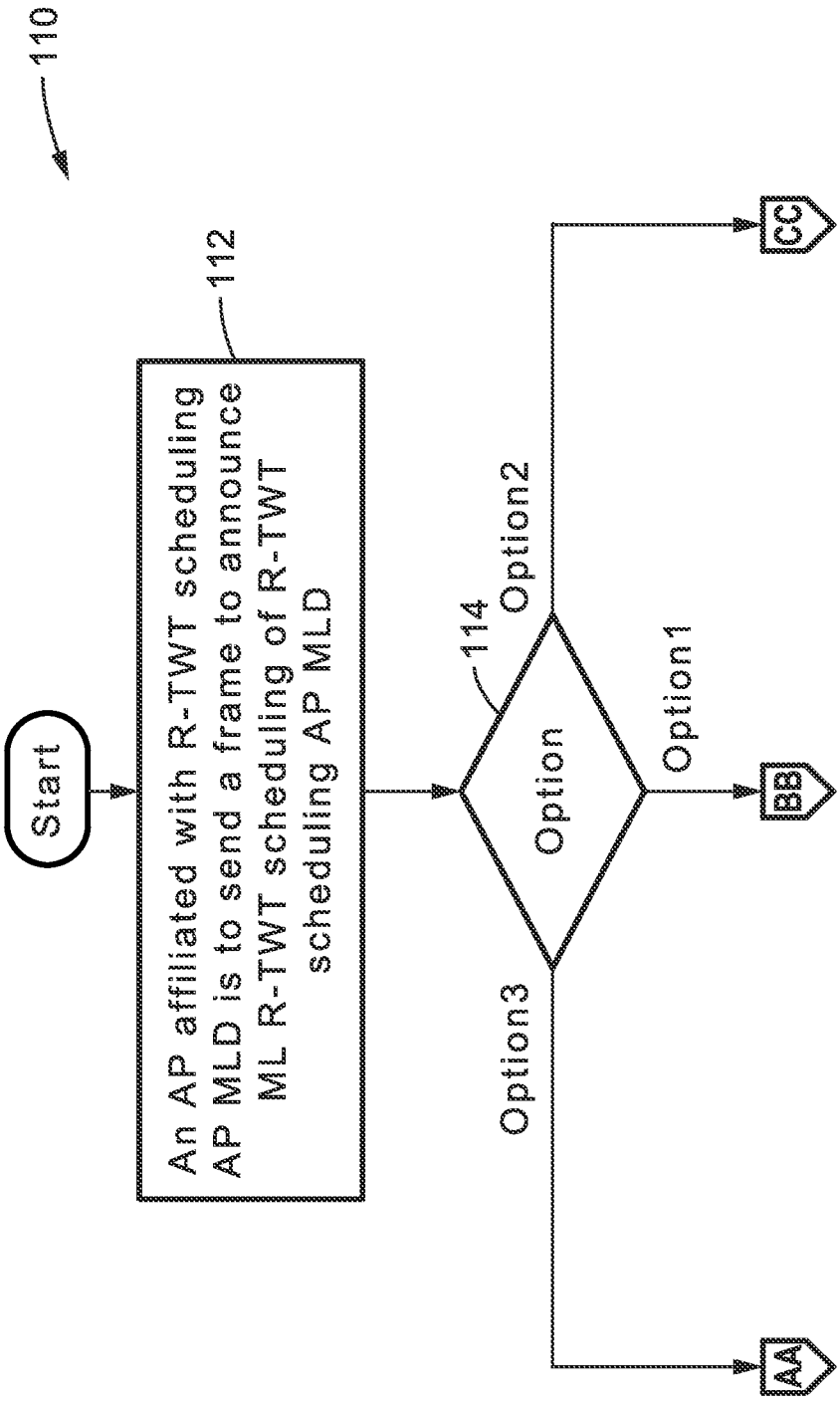

110
Start
An AP affiliated with R-TWT scheduling AP MLD is to send a frame to announce ML R-TWT scheduling of R-TWT scheduling AP MLD
112
Option
114
Option1
Option2
Option3
BB
CC
AA

FIG. 17

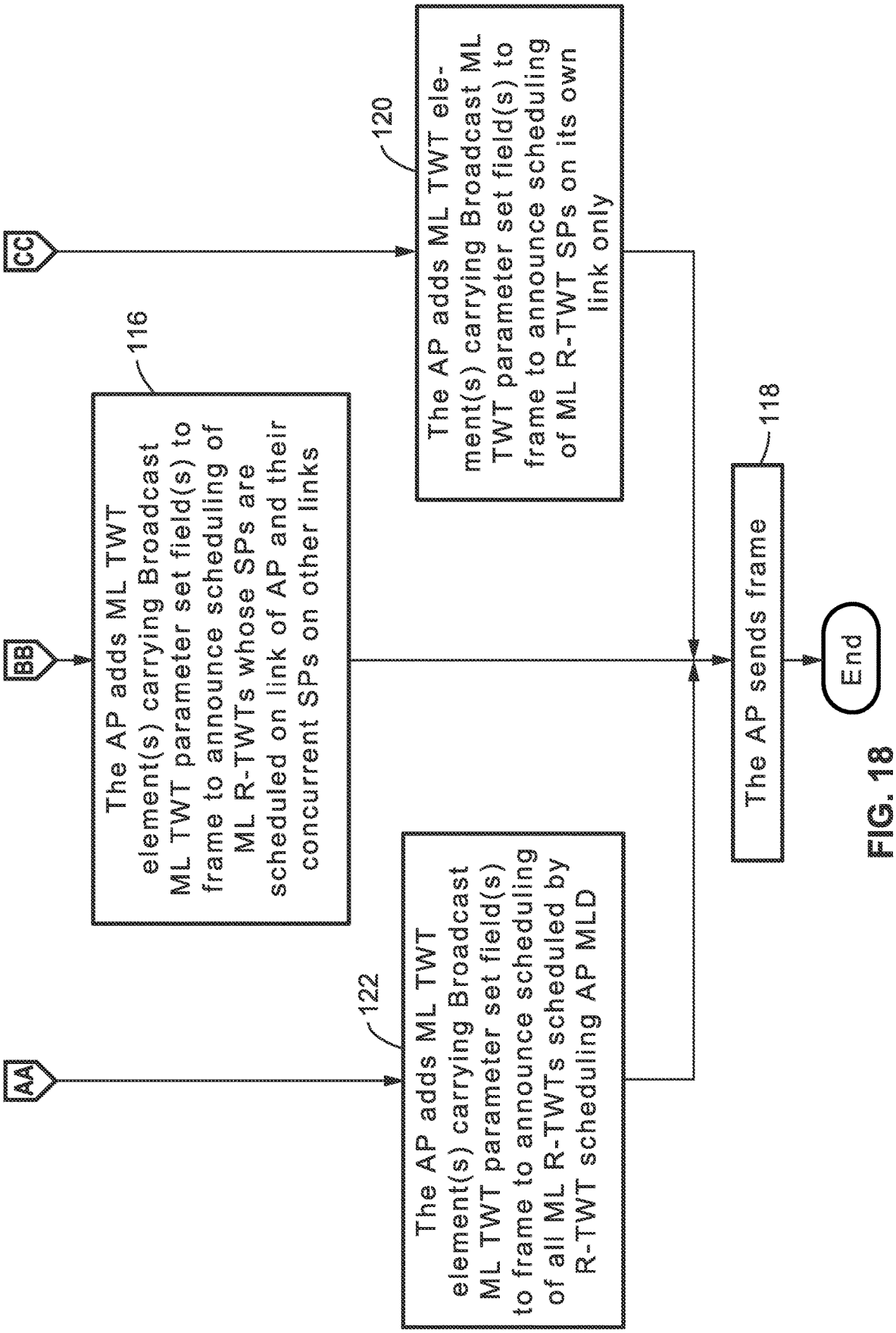

AA
BB
CC
The AP adds ML TWT element(s) carrying Broadcast ML TWT parameter set field(s) to frame to announce scheduling of ML R-TWTs whose SPs are scheduled on link of AP and their concurrent SPs on other links
116
The AP adds ML TWT element(s) carrying Broadcast ML TWT parameter set field(s) to frame to announce scheduling of ML R-TWT SPs on its own link only
120
The AP adds ML TWT element(s) carrying Broadcast ML TWT parameter set field(s) to frame to announce scheduling of all ML R-TWTs scheduled by R-TWT scheduling AP MLD
122
The AP sends frame
118
End

FIG. 18

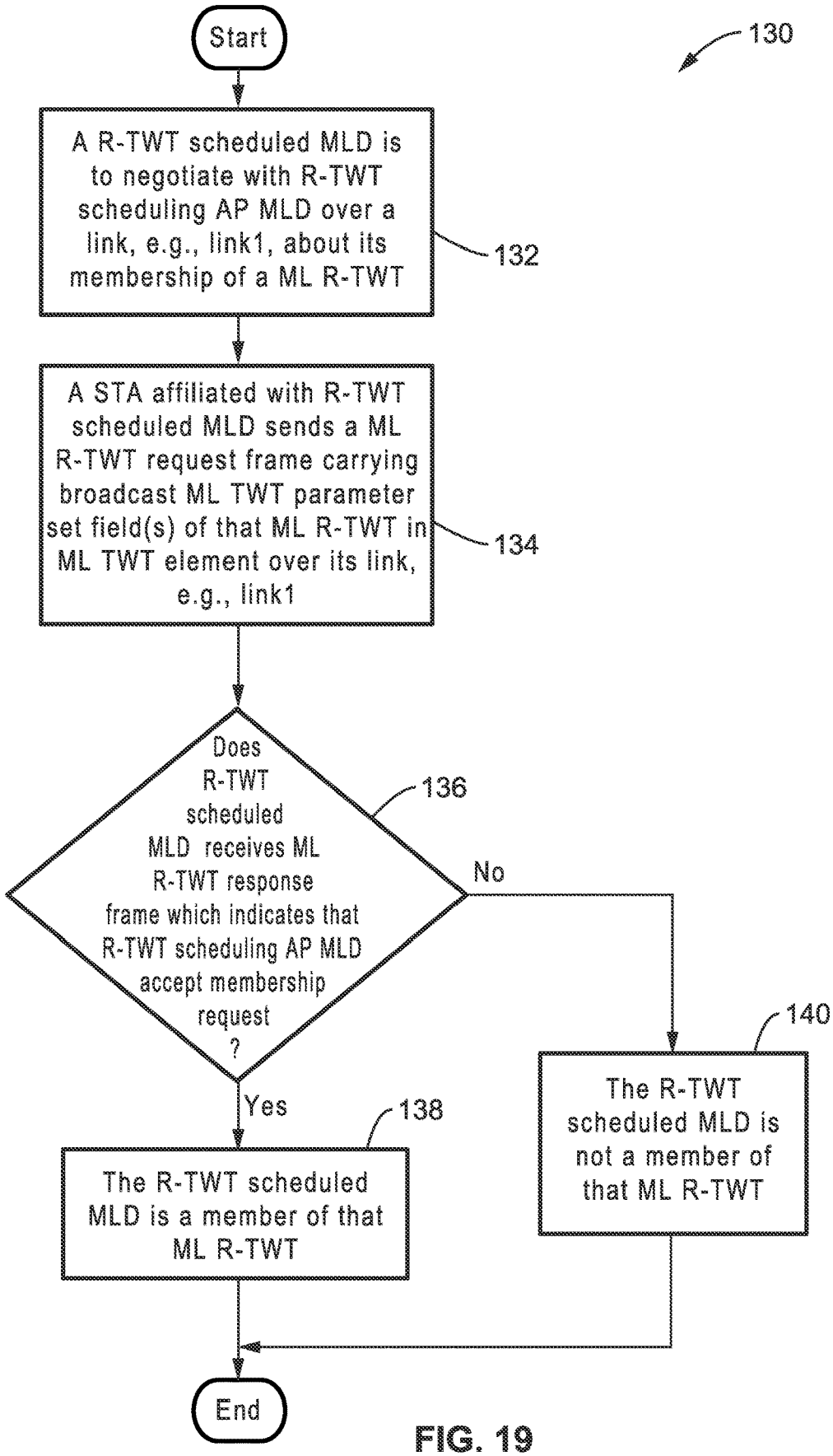

Start
130
A R-TWT scheduled MLD is to negotiate with R-TWT scheduling AP MLD over a link, e.g., link1, about its membership of a ML R-TWT
132
A STA affiliated with R-TWT scheduled MLD sends a ML R-TWT request frame carrying broadcast ML TWT parameter set field(s) of that ML R-TWT in ML TWT element over its link, e.g., link1
134
Does R-TWT scheduled MLD receives ML R-TWT response frame which indicates that R-TWT scheduling AP MLD accept membership request ?
136
No
Yes
138
The R-TWT scheduled MLD is a member of that ML R-TWT
140
The R-TWT scheduled MLD is not a member of that ML R-TWT
End

FIG. 19

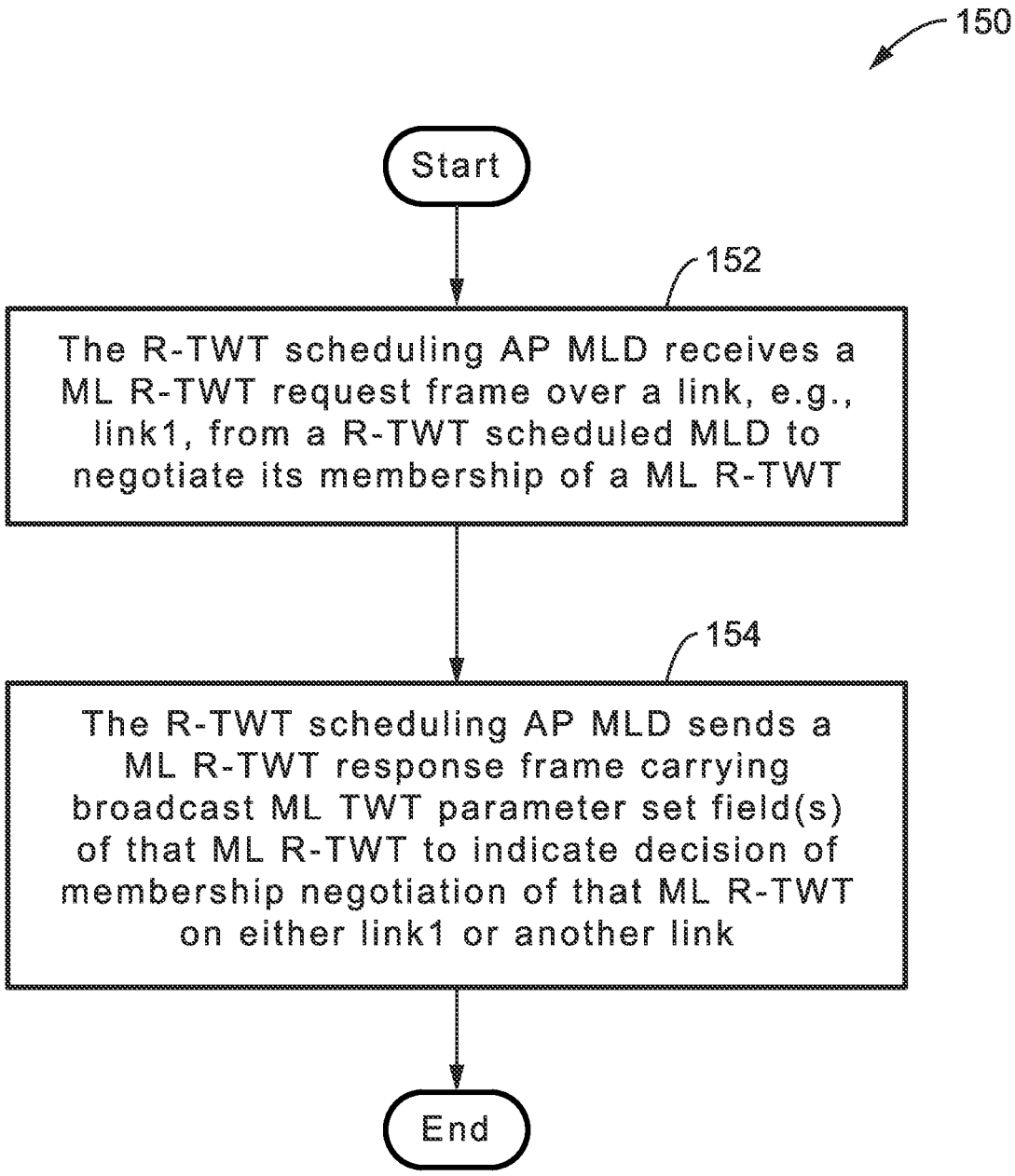

150
Start
152
The R-TWT scheduling AP MLD receives a ML R-TWT request frame over a link, e.g., link1, from a R-TWT scheduled MLD to negotiate its membership of a ML R-TWT
154
The R-TWT scheduling AP MLD sends a ML R-TWT response frame carrying broadcast ML TWT parameter set field(s) of that ML R-TWT to indicate decision of membership negotiation of that ML R-TWT on either link1 or another link
End

FIG. 20

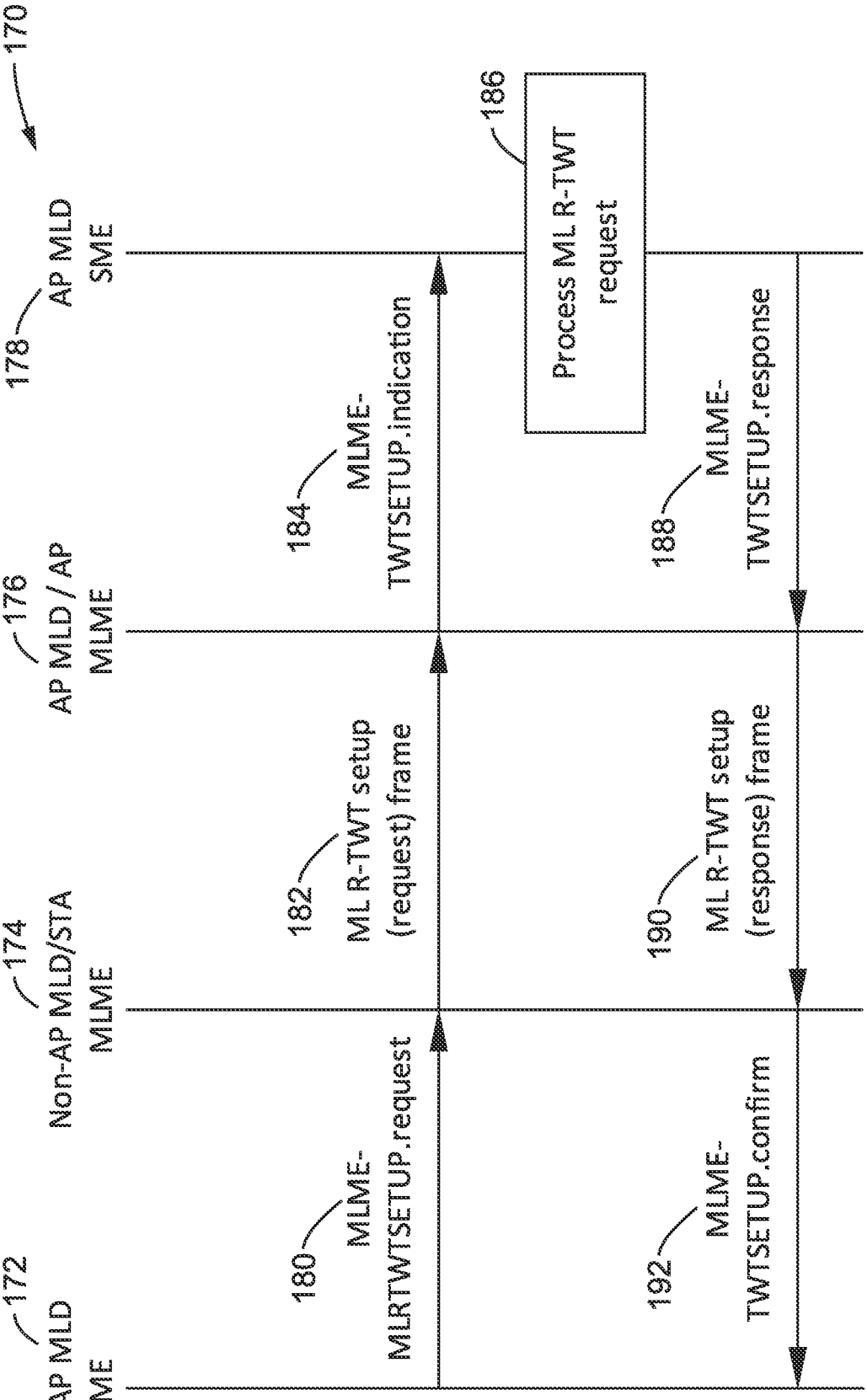

170
178
AP MLD SME
186
Process ML R-TWT request
176
AP MLD / AP MLME
184
MLME-TWTSETUP.indication
188
MLME-TWTSETUP.response
174
Non-AP MLD/STA MLME
182
ML R-TWT setup (request) frame
190
ML R-TWT setup (response) frame
172
Non-AP MLD SME
180
MLME-MLRTWTSETUP.request
192
MLME-TWTSETUP.confirm

FIG. 21

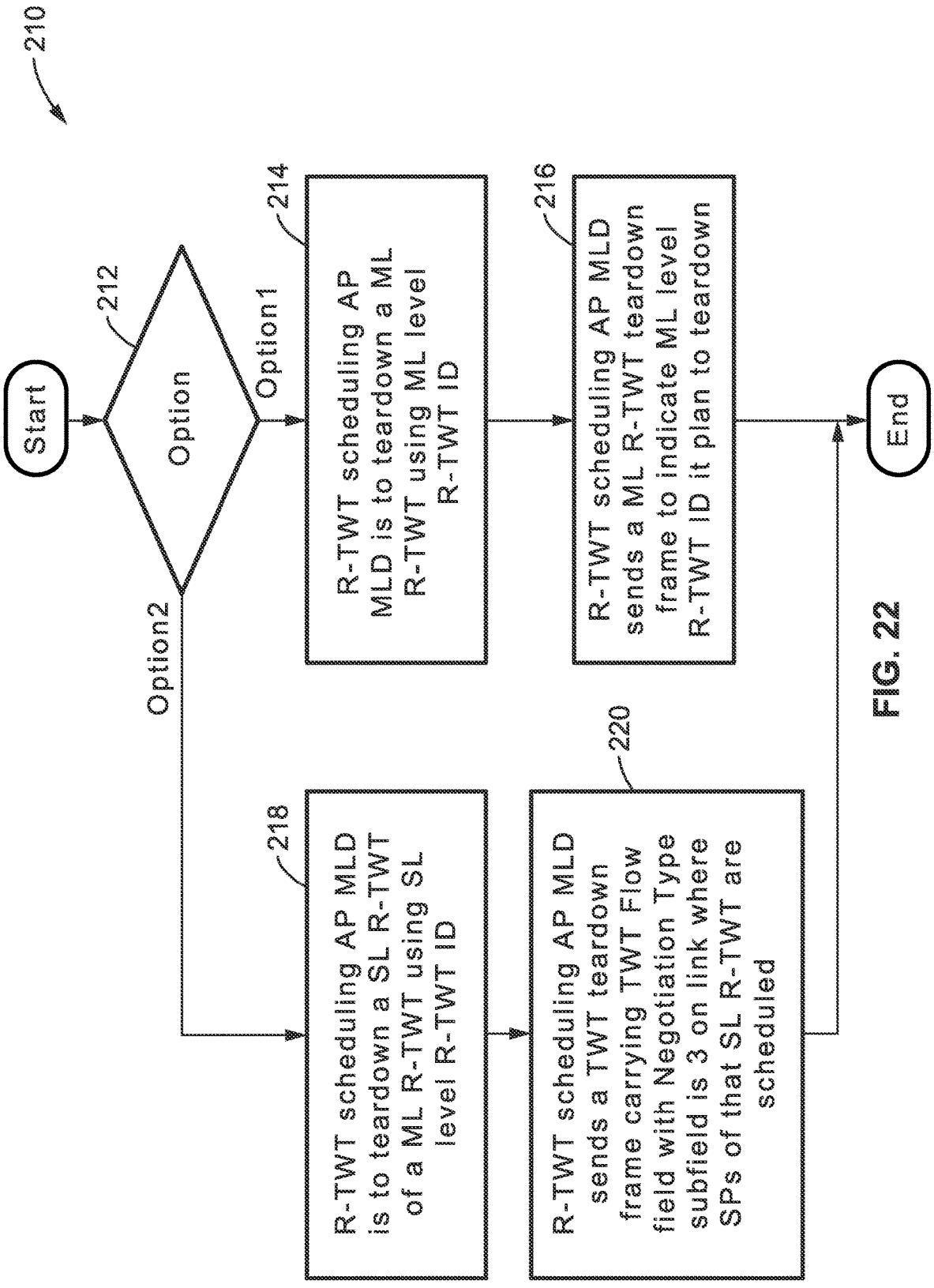

210
Start
212
Option
Option1
Option2
214
R-TWT scheduling AP MLD is to teardown a ML R-TWT using ML level R-TWT ID
216
R-TWT scheduling AP MLD sends a ML R-TWT teardown frame to indicate ML level R-TWT ID it plan to teardown
218
R-TWT scheduling AP MLD is to teardown a SL R-TWT of a ML R-TWT using SL level R-TWT ID
220
R-TWT scheduling AP MLD sends a TWT teardown frame carrying TWT Flow field with Negotiation Type subfield is 3 on link where SPs of that SL R-TWT are scheduled
End

FIG. 22

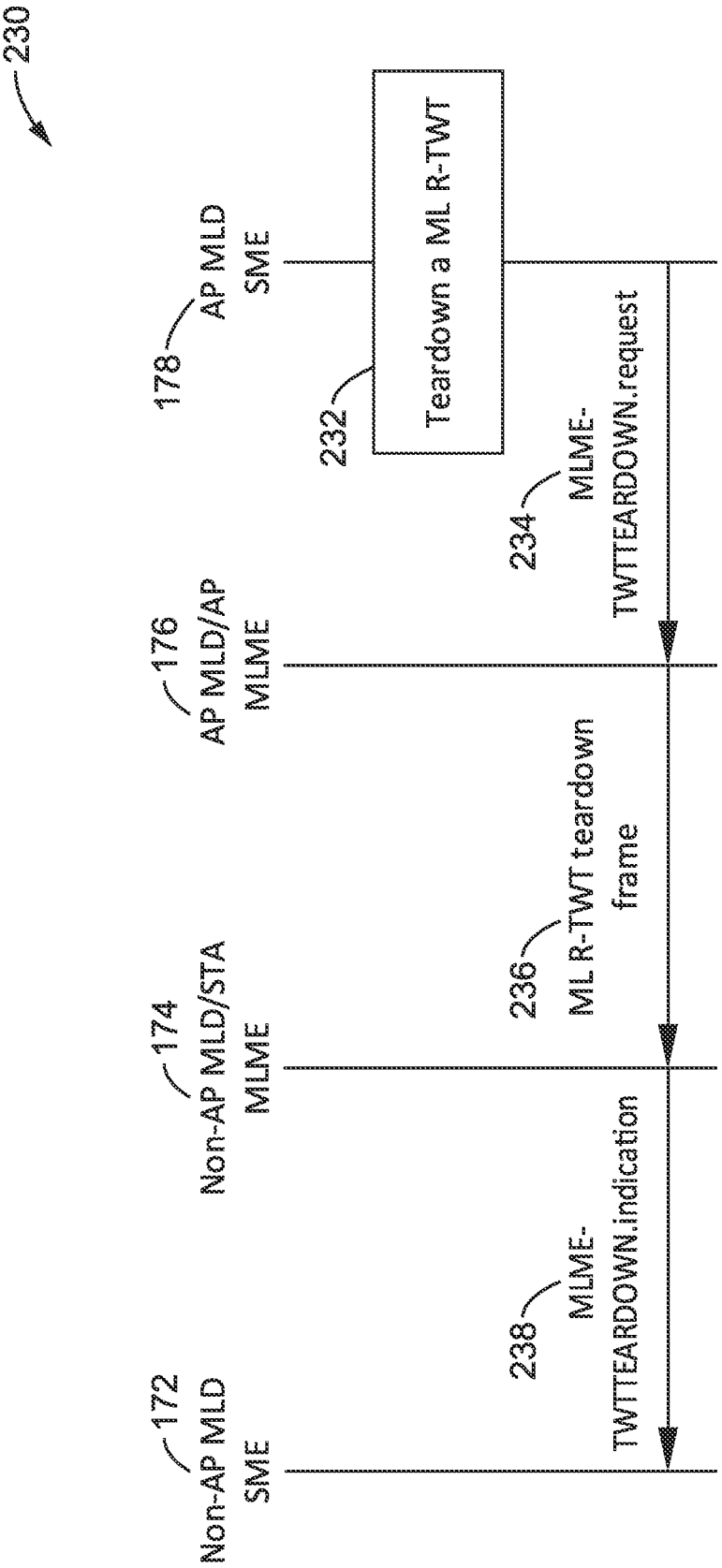

230
178
AP MLD SME
232
Teardown a ML R-TWT
234
MLME-TWTTEARDOWN.request
176
AP MLD/AP MLME
236
ML R-TWT teardown frame
174
Non-AP MLD/STA MLME
238
MLME-TWTTEARDOWN.indication
172
Non-AP MLD SME

FIG. 23

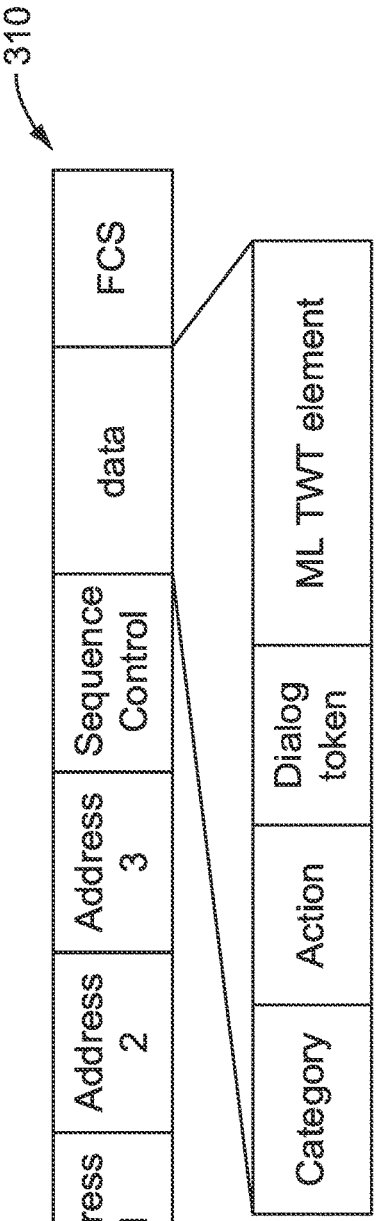

310
ML R-TWT Setup Frame
Frame Control
Duration
Address 1
Address 2
Address 3
Sequence Control
data
FCS
Category
Action
Dialog token
ML TWT element

FIG. 24

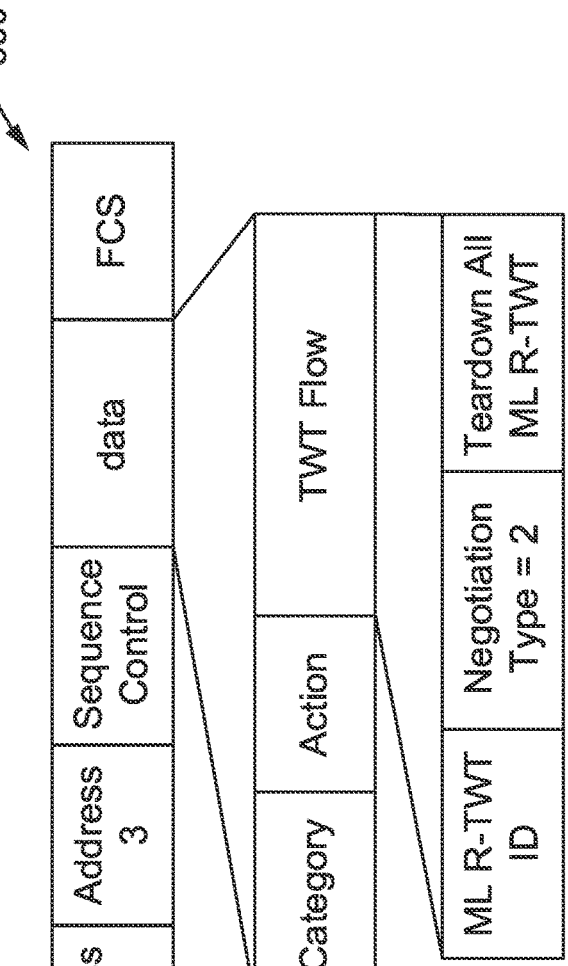

330
ML R-TWT Teardown Frame
Frame Control
Duration
Address 1
Address 2
Address 3
Sequence Control
data
FCS
Category
Action
TWT Flow
ML R-TWT ID
Negotiation Type = 2
Teardown All ML R-TWT

FIG. 25

FIG. 26

FIG. 27

FIG. 28

FIG. 29

FIG. 30

FIG. 31

FIG. 32

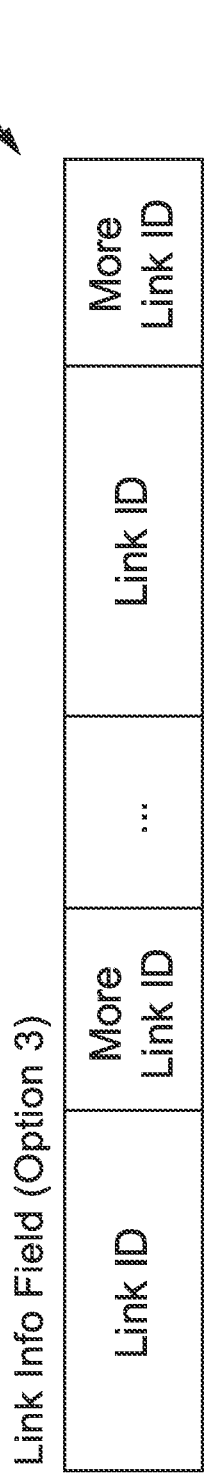


FIG. 33

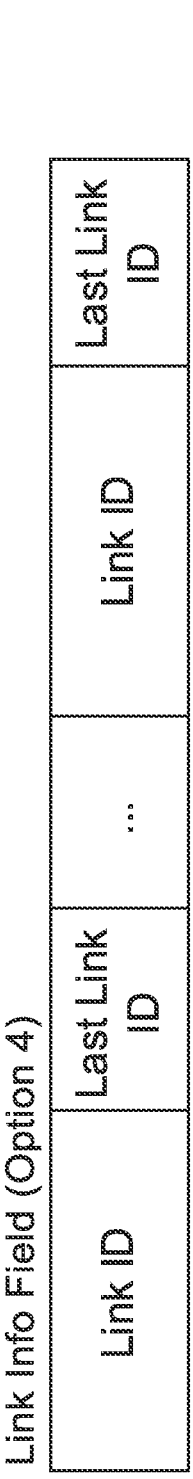


FIG. 34

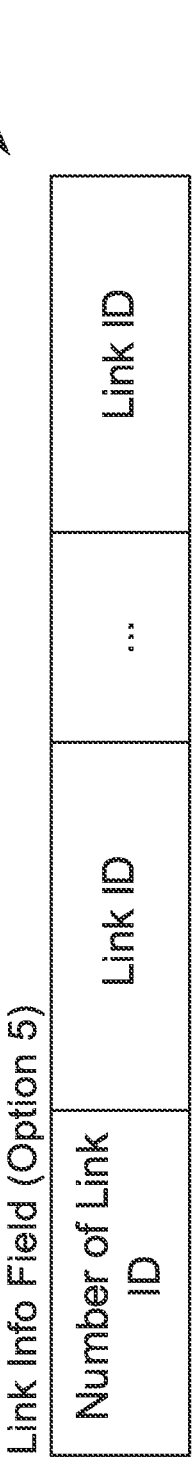


FIG. 35

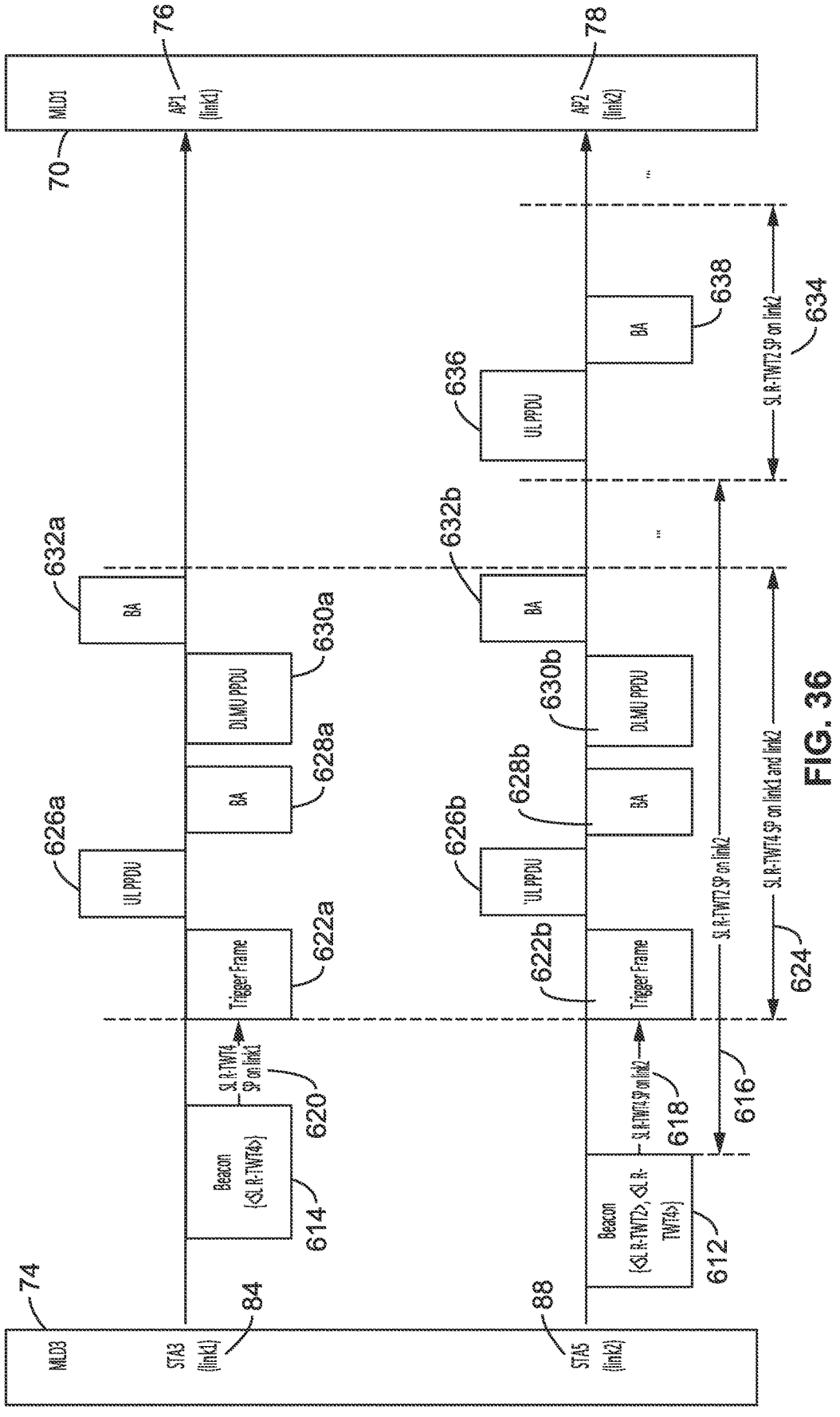

610
MLD1
70
AP1 (link1)
76
AP2 (link2)
78
MLD3
74
STA3 (link1)
84
STA5 (link2)
88
Beacon (<SL R-TWT4>)
614
SL R-TWT4 SP on link1
620
Trigger Frame
622a
UL PPDU
626a
DLMU PPDU
630a
BA
628a
BA
632a
SL R-TWT4 SP on link1 and link2
624
Beacon (<SL R-TWT2>, <SL R-TWT4>)
612
SL R-TWT4 SP on link2
618
Trigger Frame
622b
UL PPDU
626b
DLMU PPDU
630b
BA
628b
BA
632b
SL R-TWT2 SP on link2
616
UL PPDU
636
BA
638
SL R-TWT2 SP on link2
634

FIG. 36

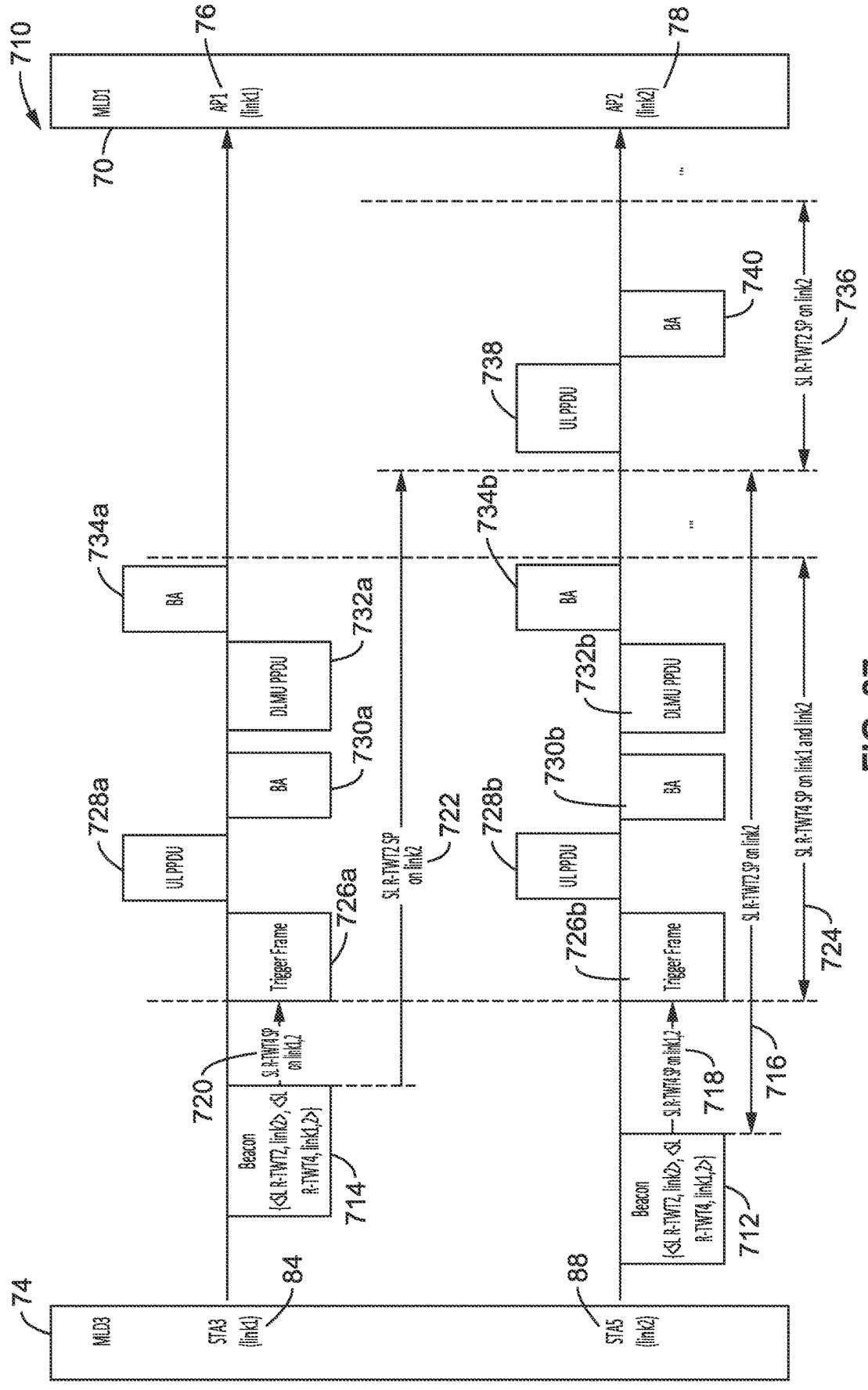

710
MLD1
70
76
AP1
(link1)
78
AP2
(link2)
MLD3
74
STA3
(link1)
84
STA5
(link2)
88
Beacon
(<SL R-TWT2, link2>, <SL R-TWT4, link4,2>)
712
714
SL R-TWT4 SP on link2
718
716
Trigger Frame
726a
726b
UL PPDU
728a
728b
DL MU PPDU
732a
732b
BA
730a
730b
734a
734b
SL R-TWT2 SP on link2
722
SL R-TWT4 SP on link1 and link2
724
SL R-TWT2 SP on link2
736
UL PPDU
738
BA
740

FIG. 37

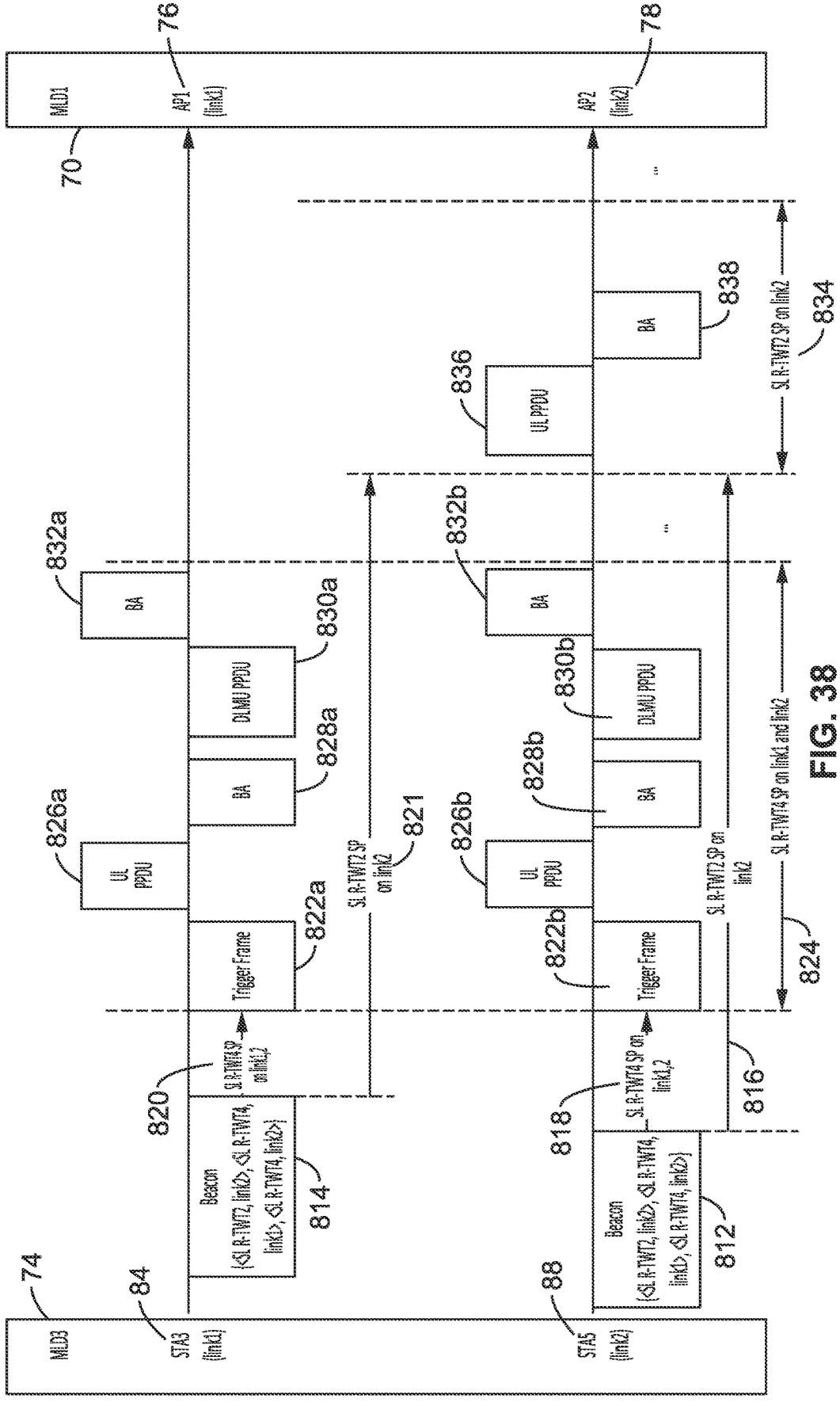

810
MLD1
70
AP1 (link1)
76
AP2 (link2)
78
MLD3
74
STA3 (link1)
84
STA5 (link2)
88
Beacon (<SL R-TWT2, link2>, <SL R-TWT4, link2>, <SL R-TWT4, link2>)
814
SL R-TWT4 SP on link1,2
820
Trigger Frame
822a
UL PPDU
826a
DL MU PPDU
830a
BA
828a
BA
832a
SL R-TWT2 SP on link2
821
Beacon (<SL R-TWT2, link2>, <SL R-TWT4, link2>, <SL R-TWT4, link2>)
812
SL R-TWT4 SP on link1,2
818
Trigger Frame
822b
UL PPDU
826b
DL MU PPDU
830b
BA
828b
BA
832b
UL PPDU
836
BA
838
SL R-TWT2 SP on link2
834
SL R-TWT2 SP on link2
816
SL R-TWT4 SP on link1 and link2
824

FIG. 38

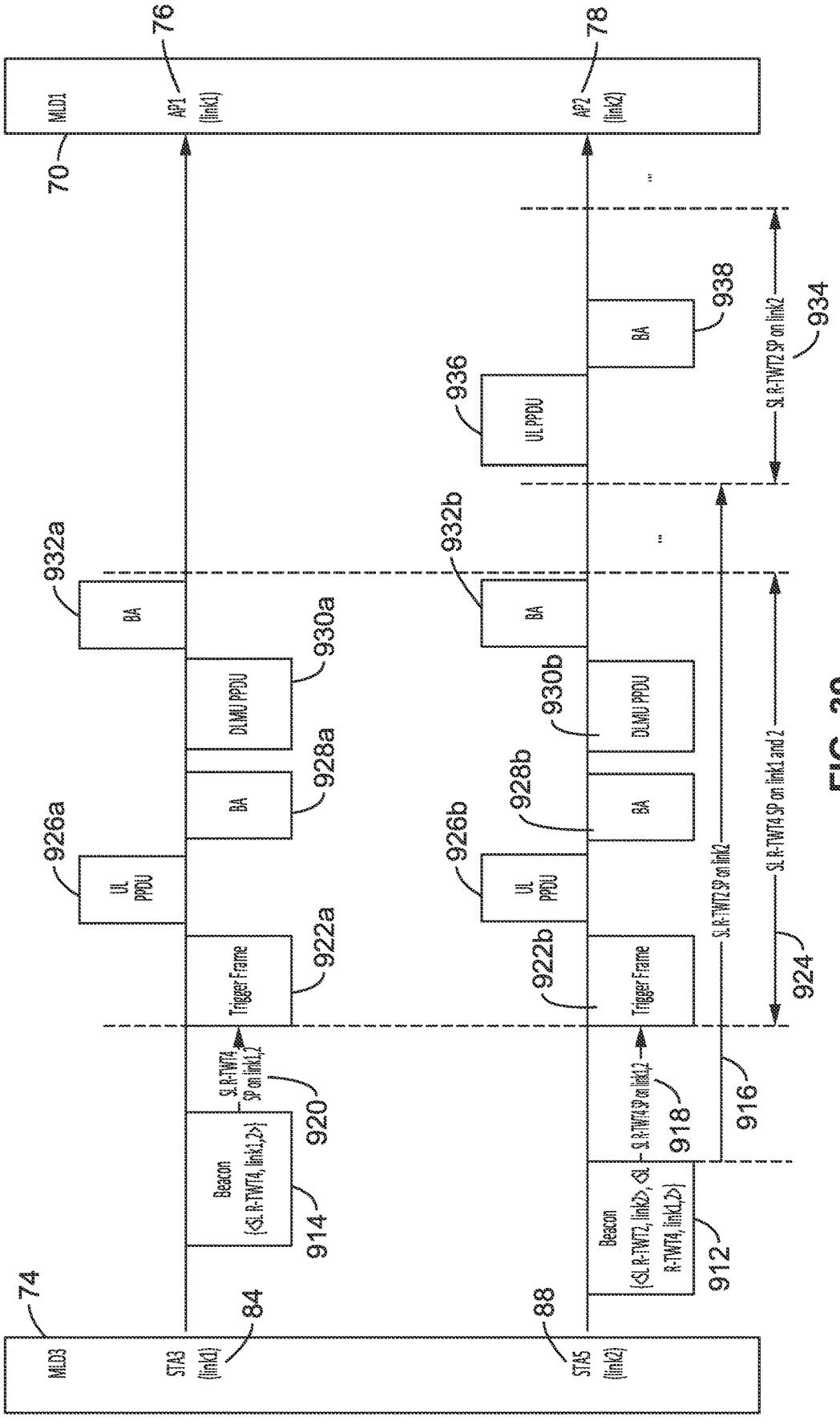

910
MLD1
70
76
AP1 (link1)
78
AP2 (link2)
MLD3
74
STA3 (link1)
84
STA5 (link2)
88
Beacon (<SL R-TWT4, link1,2>)
914
SL R-TWT4 SP on link1,2
920
Trigger Frame
922a
922b
UL PPDU
926a
926b
DL MU PPDU
930a
930b
BA
928a
928b
932a
932b
Beacon (<SL R-TWT2, link2>, <SL R-TWT4, link1,2>)
912
SL R-TWT4 SP on link1,2
918
SL R-TWT2 SP on link2
916
SL R-TWT4 SP on link1 and 2
924
UL PPDU
936
BA
938
SL R-TWT2 SP on link2
934

FIG. 39

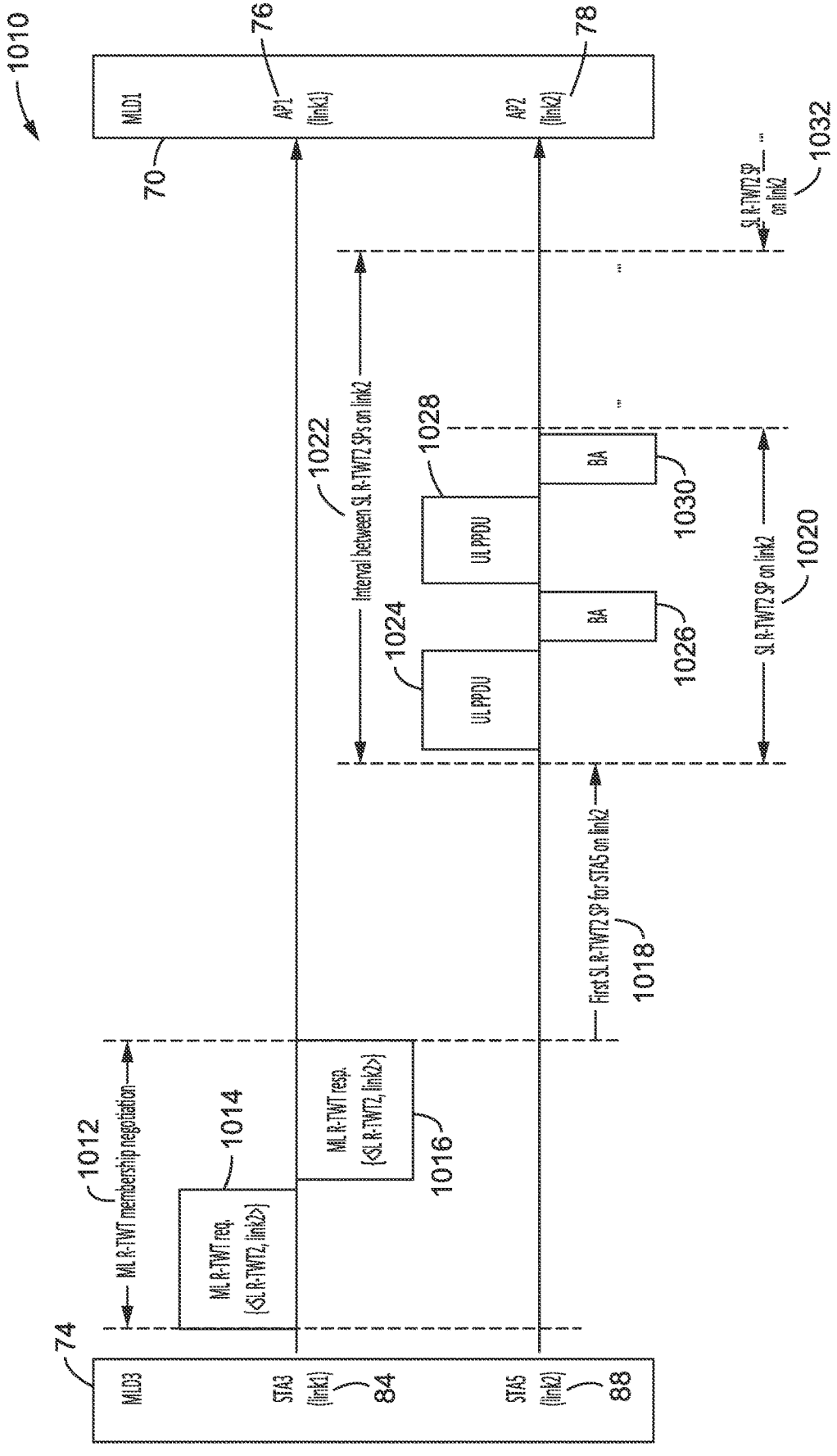

1010
MLD1
70
AP1 (link1)
76
AP2 (link2)
78
MLD3
74
STA3 (link1)
84
STA5 (link2)
88
1012
ML R-TWT membership negotiation
1014
ML R-TWT req. (<SL R-TWT2, link2>)
1016
ML R-TWT resp. (<SL R-TWT2, link2>)
1018
First SL R-TWT2 SP for STA5 on link2
1020
SL R-TWT2 SP on link2
1022
Interval between SL R-TWT2 SPs on link2
1024
UL PPDU
1026
BA
1028
UL PPDU
1030
BA
1032
SL R-TWT2 SP on link2

FIG. 40

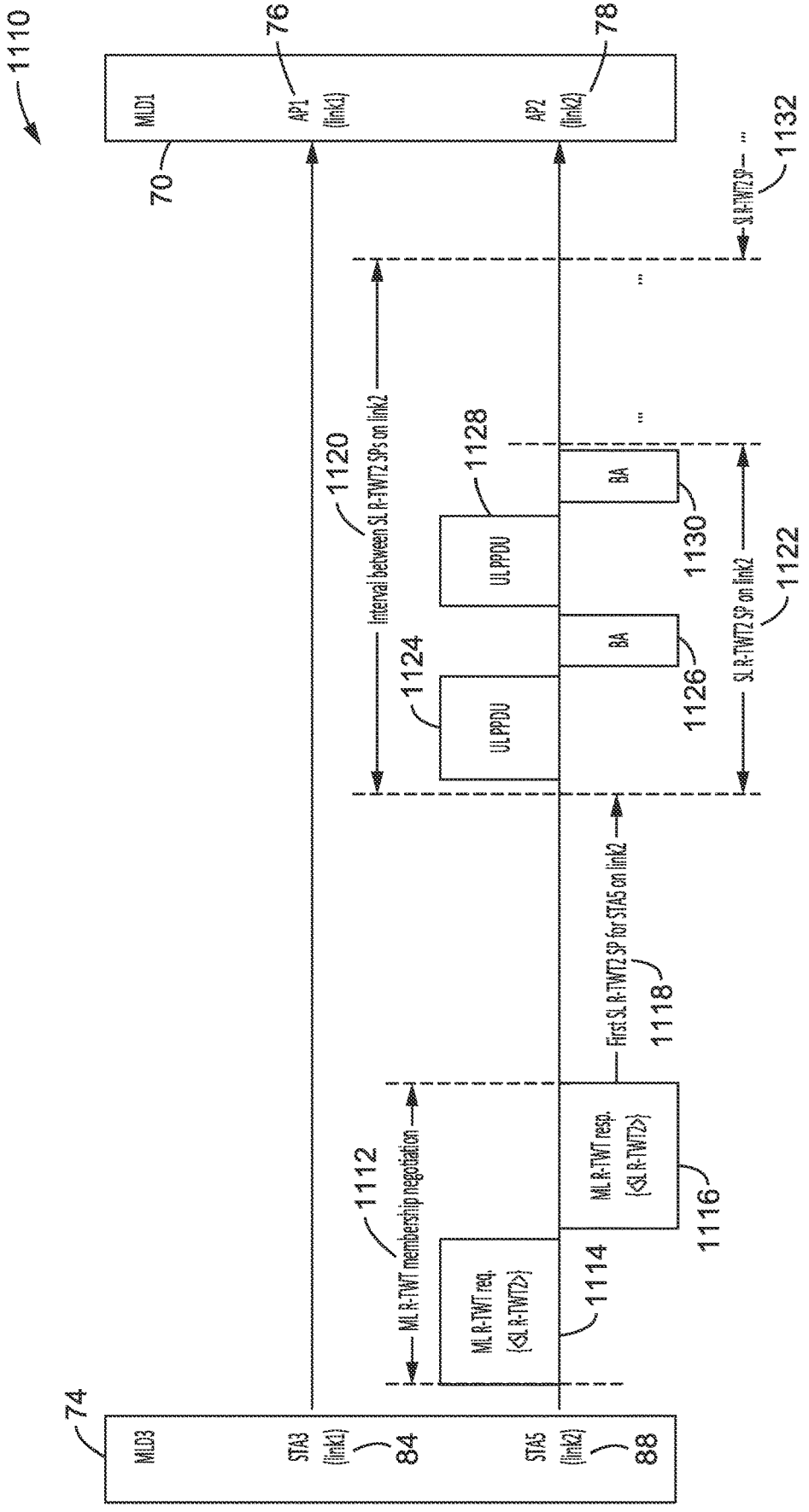

1110
MLD1
70
AP1
(link1)
76
AP2
(link2)
78
MLD3
74
STA3
(link1)
84
STA5
(link2)
88
ML R-TWT membership negotiation
1112
ML R-TWT req.
(<SL R-TWT2>)
1114
ML R-TWT resp.
(<SL R-TWT2>)
1116
First SL R-TWT2 SP for STA5 on link2
1118
Interval between SL R-TWT2 SPs on link2
1120
UL PPDU
1124
BA
1126
UL PPDU
1128
BA
1130
SL R-TWT2 SP on link2
1122
SL R-TWT2 SP
1132

FIG. 41

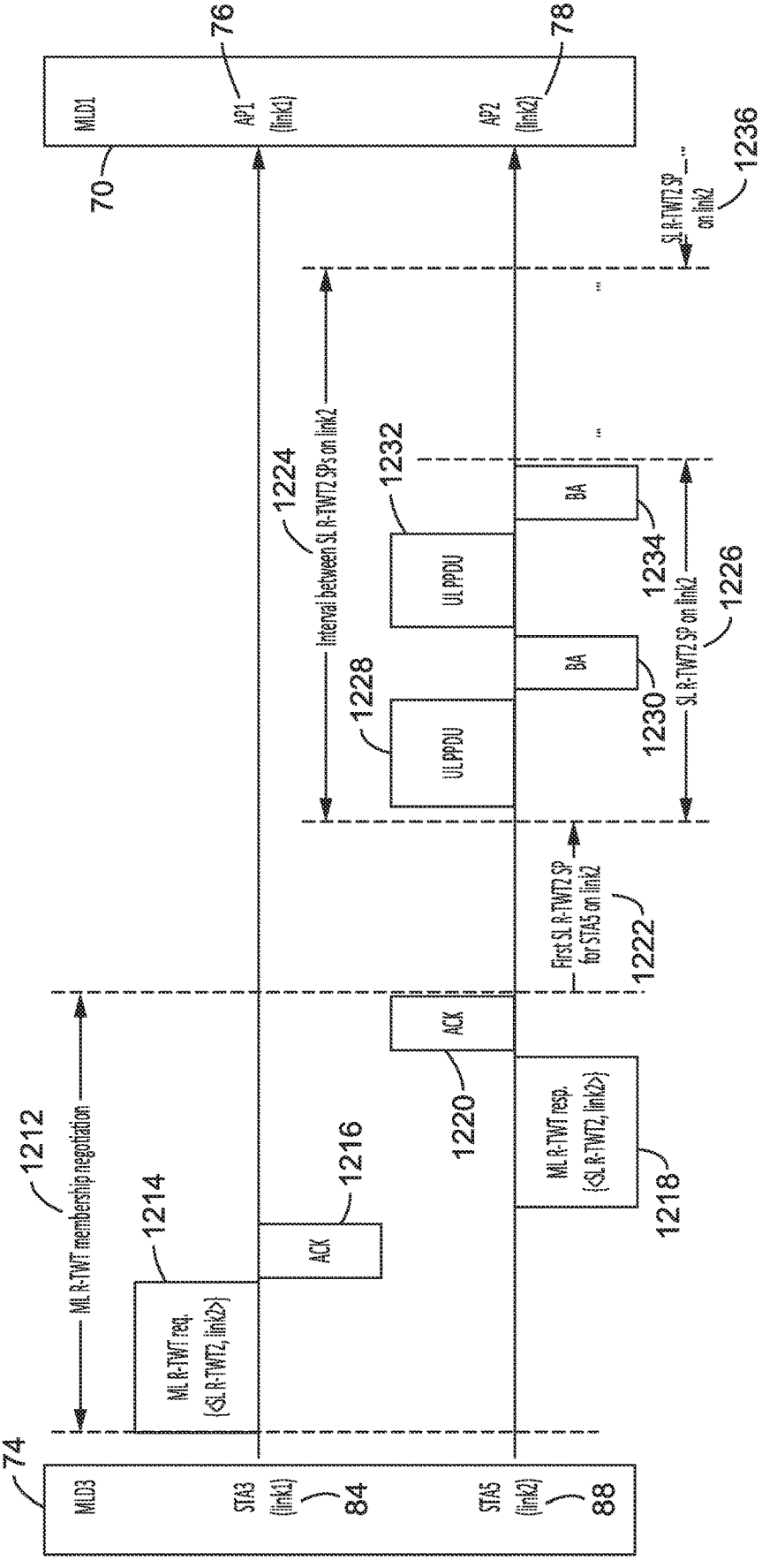

1210
MLD1
70
AP1 (link1)
76
AP2 (link2)
78
SL R-TWT2 SP on link2
1236
Interval between SL R-TWT2 SPs on link2
1224
UL PPDU
1232
BA
1234
SL R-TWT2 SP on link2
1226
UL PPDU
1228
BA
1230
First SL R-TWT2 SP for STA5 on link2
1222
ML R-TWT membership negotiation
1212
ML R-TWT req. (<SL R-TWT2, link2>)
1214
ACK
1216
ACK
1220
ML R-TWT resp. (<SL R-TWT2, link2>)
1218
MLD3
74
STA3 (link1)
84
STA5 (link2)
88

FIG. 42

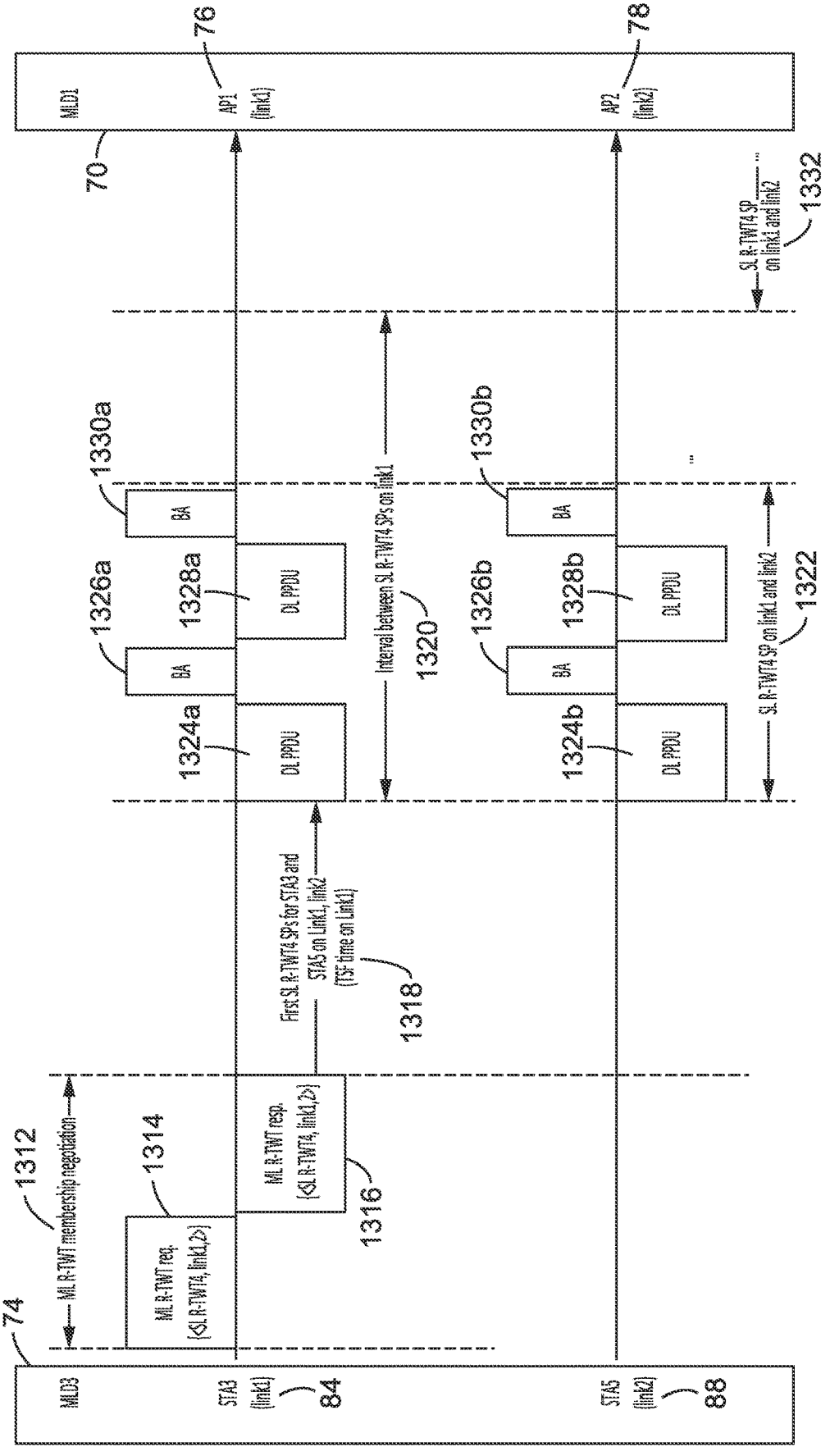

1310
MLD1
70
AP1 (link1)
76
AP2 (link2)
78
MLD3
74
STA3 (link1)
84
STA5 (link2)
88
ML R-TWT membership negotiation
1312
ML R-TWT req. (<SI, R-TWT4, link1,2>)
1314
ML R-TWT resp. (<SI, R-TWT4, link1,2>)
1316
First SL R-TWT4 SPs for STA3 and STA5 on Link1, link2 (TSF time on Link1)
1318
Interval between SL R-TWT4 SPs on link1
1320
SL R-TWT4 SP on link1 and link2
1322
SL R-TWT4 SP on link1 and link2
1332
1324a
DL PPDU
1324b
DL PPDU
1326a
BA
1326b
BA
1328a
DL PPDU
1328b
DL PPDU
1330a
BA
1330b
BA

FIG. 43

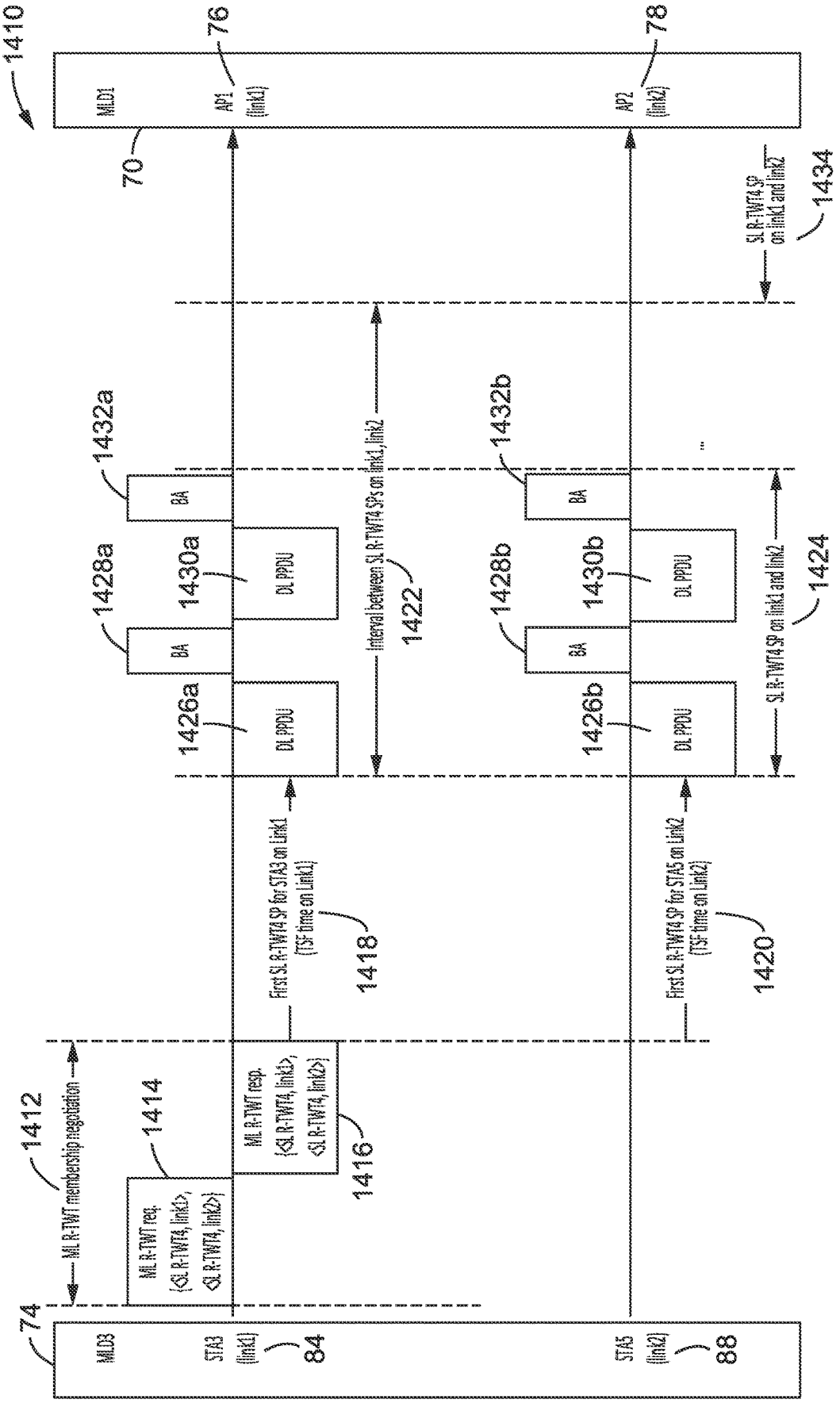

1410
MLD1
70
AP1
(link1)
76
AP2
(link2)
78
MLD3
74
STA3
(link1)
84
STA5
(link2)
88
ML R-TWT membership negotiation
1412
ML R-TWT req.
{SL R-TWT4, link1>,
<SL R-TWT4, link2>}
1414
ML R-TWT resp.
{<SL R-TWT4, link1>,
<SL R-TWT4, link2>}
1416
First SL R-TWT4 SP for STA3 on Link1
(TSF time on Link1)
1418
First SL R-TWT4 SP for STA5 on Link2
(TSF time on Link2)
1420
SL R-TWT4 SP on link1 and link2
1424
SL R-TWT4 SP on link1 and link2
1434
Interval between SL R-TWT4 SPs on link1, link2
1422
1426a
DL PPDU
1428a
BA
1430a
DL PPDU
1432a
BA
1426b
DL PPDU
1428b
BA
1430b
DL PPDU
1432b
BA

FIG. 44

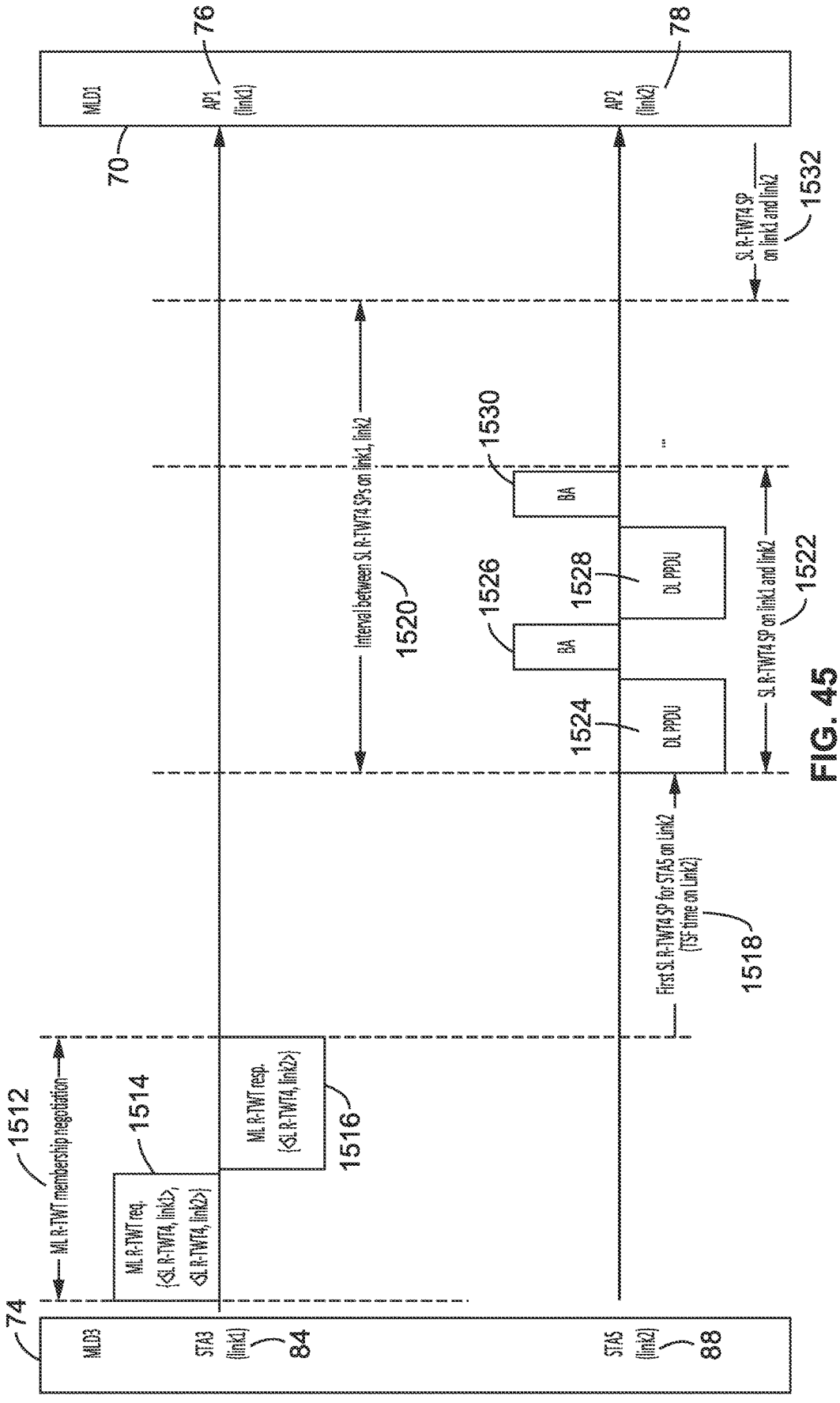

1510
MLD1
70
AP1
(link1)
76
AP2
(link2)
78
MLD3
74
STA3
(link1)
84
STA5
(link2)
88
ML R-TWT membership negotiation
1512
ML R-TWT req.
(<SL R-TWT4, link1>,
<SL R-TWT4, link2>)
1514
ML R-TWT resp.
(<SL R-TWT4, link2>)
1516
First SL R-TWT4 SP for STA5 on Link2
(TSF time on Link2)
1518
Interval between SL R-TWT4 SPs on link1, link2
1520
DL PPDU
1524
BA
1526
DL PPDU
1528
BA
1530
SL R-TWT4 SP on link1 and link2
1522
SL R-TWT4 SP on link1 and link2
1532

FIG. 45

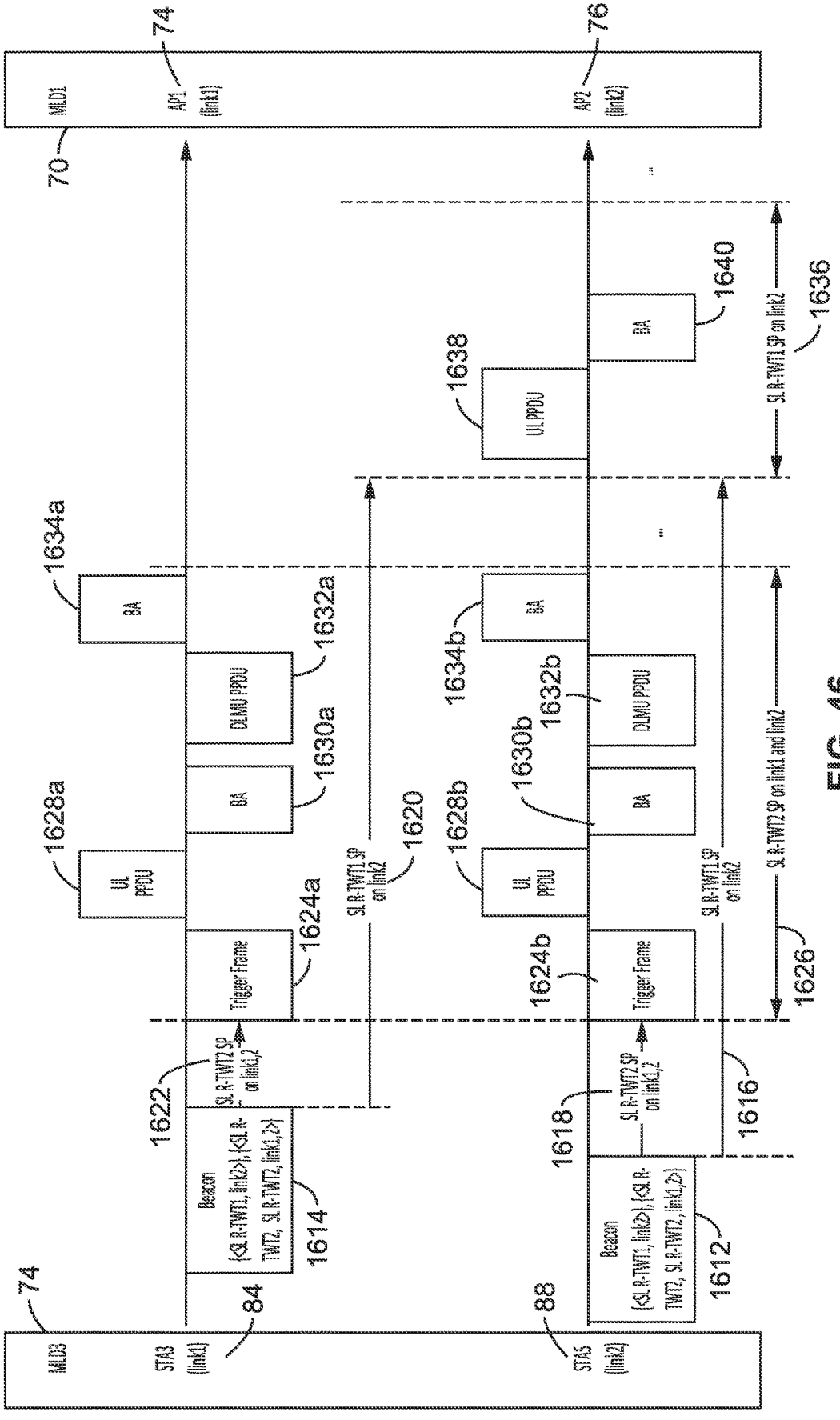

1610
MLD1
70
74
AP1 (link1)
76
AP2 (link2)
MLD3
74
STA3 (link1)
84
STA5 (link2)
88
Beacon (<SL R-TWT1, link2>), (<SL R-TWT2, SL R-TWT2, link1,2>)
1614
1612
SL R-TWT2 SP on link1,2
1622
1618
Trigger Frame
1624a
1624b
UL PPDU
1628a
1628b
DL MU PPDU
1632a
1632b
BA
1630a
1630b
1634a
1634b
1640
UL PPDU
1638
SL R-TWT1 SP on link2
1620
SL R-TWT1 SP on link2
1636
SL R-TWT2 SP on link1 and link2
1626
1616

FIG. 46

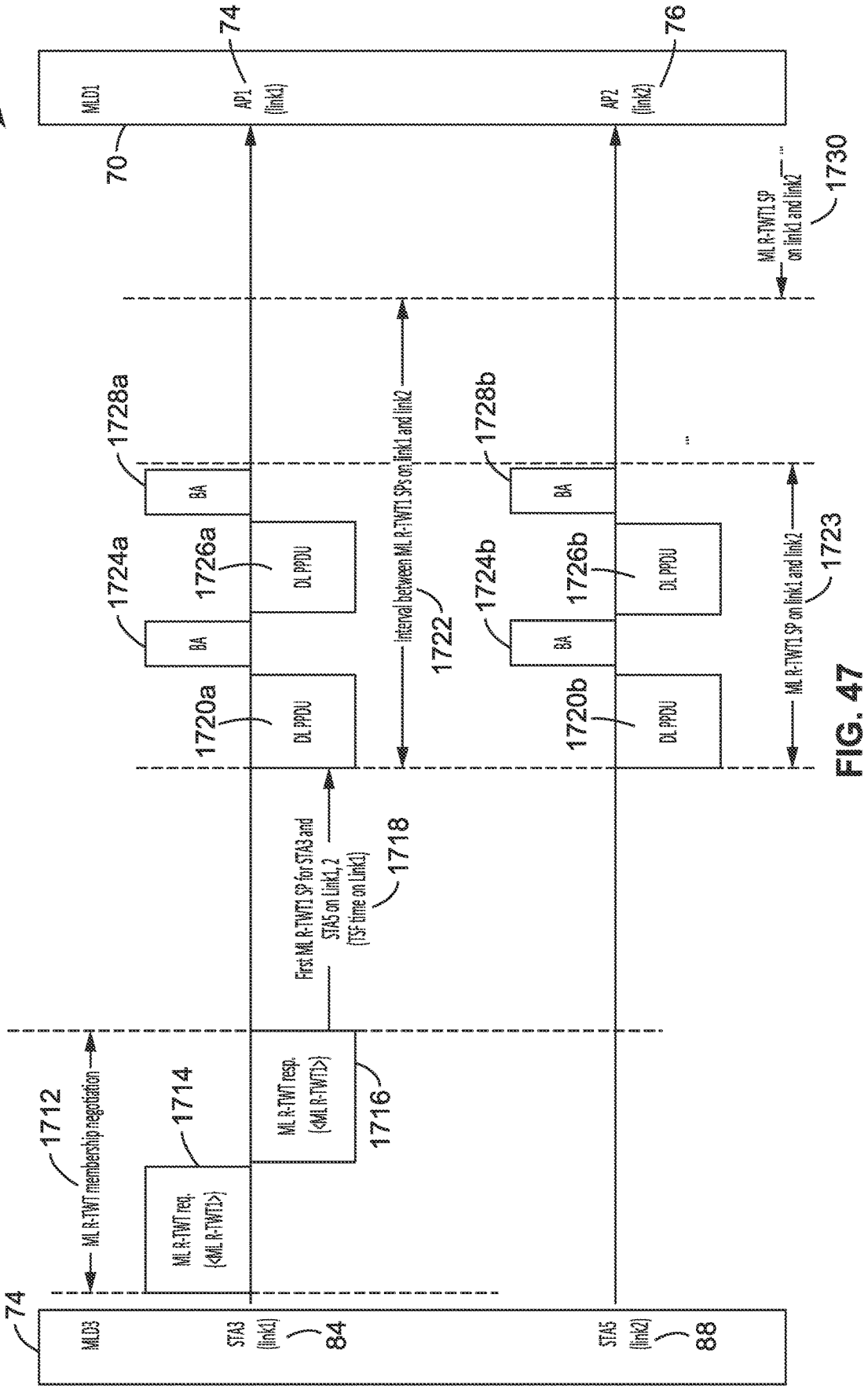

1710
MLD1
70
74
AP1 (link1)
76
AP2 (link2)
1730
ML R-TWT1 SP on link1 and link2
1728a
1728b
BA
1724a
1724b
1726a
1726b
DL PPDU
1720a
1720b
interval between ML R-TWT1 SPs on link1 and link2
1722
1723
ML R-TWT1 SP on link1 and link2
First ML R-TWT1 SP for STA3 and STA5 on Link1, 2 (TSF time on Link1)
1718
ML R-TWT membership negotiation
1712
ML R-TWT req. (<ML R-TWT1>)
1714
ML R-TWT resp. (<ML R-TWT1>)
1716
MLD3
74
STA3 (link1)
84
STA5 (link2)
88

FIG. 47

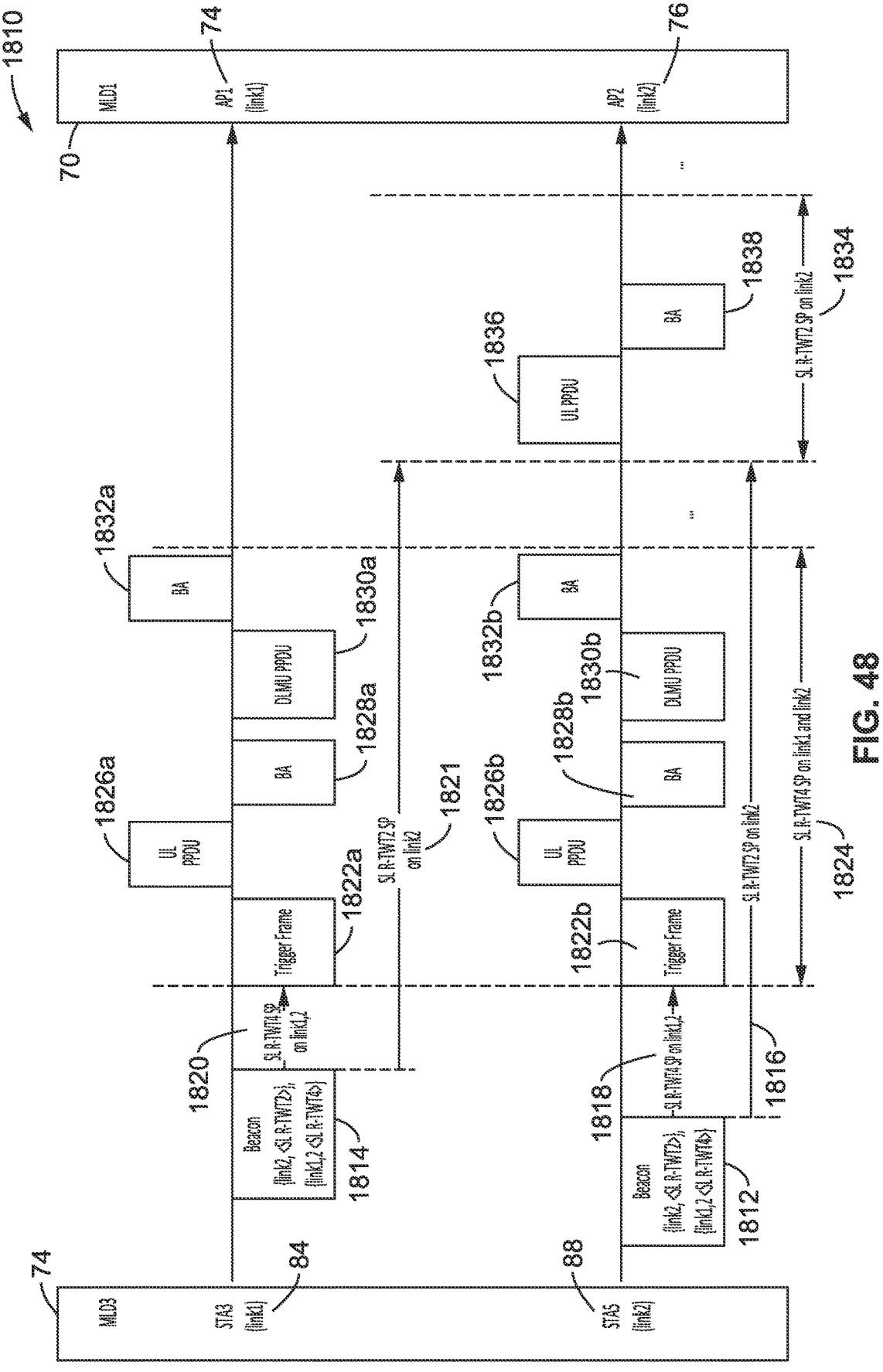

1810
70
MLD1
74
AP1 (link1)
AP2 (link2)
76
MLD3
74
STA3 (link1)
84
STA5 (link2)
88
Beacon (link2, <SL R-TWT2>), (link1,2 <SL R-TWT4>)
1814
SL R-TWT4 SP on link1,2
1820
Trigger Frame
1822a
UL PPDU
1826a
BA
1828a
DL MU PPDU
1830a
BA
1832a
SL R-TWT2 SP on link2
1821
Beacon (link2, <SL R-TWT2>), (link1,2 <SL R-TWT4>)
1812
SL R-TWT4 SP on link1,2
1818
Trigger Frame
1822b
UL PPDU
1826b
BA
1828b
DL MU PPDU
1830b
BA
1832b
UL PPDU
1836
BA
1838
SL R-TWT2 SP on link2
1834
SL R-TWT2 SP on link2
SL R-TWT4 SP on link1 and link2
1824
1816

FIG. 48

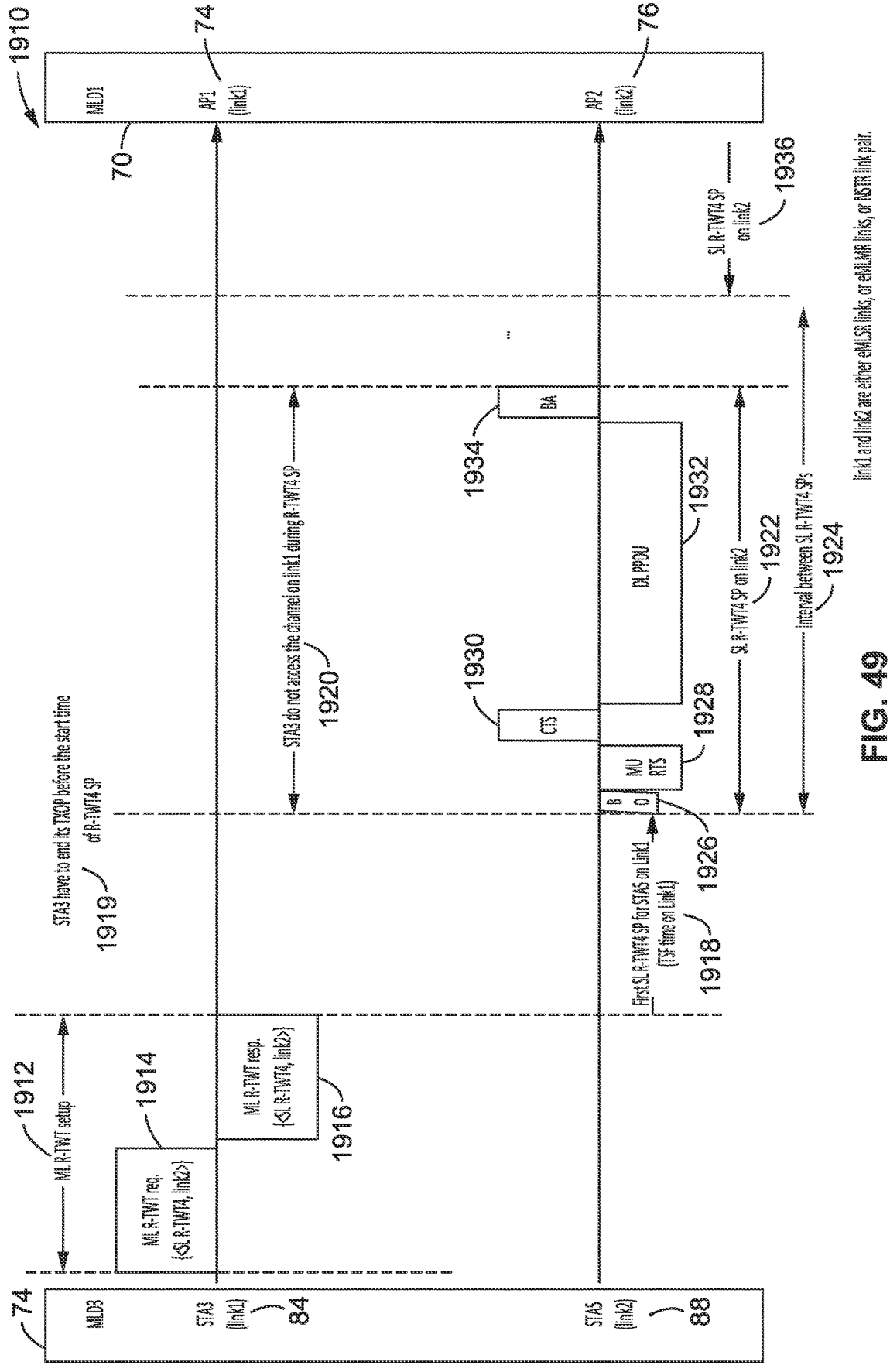

1910
74
76
MLD1
AP1 (link1)
AP2 (link2)
70
1936
SL R-TWT SP on link2
BA
1934
1932
DL PPDU
1930
CTS
1928
MU RTS
1922
SL R-TWT SP on link2
1924
Interval between SL R-TWT SPs
link1 and link2 are either eMLSR links, or eMLMR links, or NSTR link pair.
STA3 do not access the channel on link1 during R-TWT SP
1920
STA3 have to end its TXOP before the start time of R-TWT SP
1919
1926
First SL R-TWT SP for STA5 on Link1 (TSF time on Link1)
1918
1912
ML R-TWT setup
1914
ML R-TWT req. (<SL R-TWT4, link2>)
1916
ML R-TWT resp. (<SL R-TWT4, link2>)
74
MLD3
STA3 (link1)
84
STA5 (link2)
88

FIG. 49

MULTI-LINK RESTRICTED TWT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to, and the benefit of, U.S. provisional patent application Ser. No. 63/263,340 filed on Nov. 1, 2021, incorporated herein by reference in its entirety.

NOTICE OF MATERIAL SUBJECT TO COPYRIGHT PROTECTION

A portion of the material in this patent document may be subject to copyright protection under the copyright laws of the United States and of other countries. The owner of the copyright rights has no objection to the facsimile reproduction by anyone of the patent document or the patent disclosure, as it appears in the United States Patent and Trademark Office publicly available file or records, but otherwise reserves all copyright rights whatsoever. The copyright owner does not hereby waive any of its rights to have this patent document maintained in secrecy, including without limitation its rights pursuant to 37 C.F.R. § 1.14.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable

BACKGROUND

1. Technical Field

The technology of this disclosure pertains generally to wireless local area networks using CSMA/CA, and more particularly to MLD R-TWT scheduling of a Multi-Link (ML) R-TWT with Service Periods (SPs) on multiple links.

2. Background Discussion

Current wireless technologies using Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) focus principally on high throughput performance of the network, however, these lack low latency capability. However, an increasing number of applications, such as Real Time Applications (RTA), require low latency; and thus, there is a technology gap.

The RTA requires low latency communication and uses best effort communications. The data generated from the RTA is called RTA traffic and will be packetized as RTA frame(s) at the transmitter STA. Also, the data generated from the non-time sensitive application is called non-RTA traffic and will be packetized as non-RTA frame(s) at the transmitter STA. Then, the transmitter STA transmits packets carrying frames to the receiver STA over the channel.

The RTA frame requires low latency due to its high timeliness requirements on delivery. The RTA frame is valid when it is delivered within a certain period of time. One solution in the CSMA/CA wireless technology is to schedule a Service Period (SP) of Restricted Target Wake Time (R-TWT) for the RTA frame exchange. During the R-TWT SPs, the RTA frames have higher priority to transmit than other frames.

However, current implementations of the R-TWT mechanism suffer from scheduling and overhead issues. The present disclosure overcomes these issues and provide additional benefits.

BRIEF SUMMARY

A wireless local area network (WLAN) using Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) and scheduling a Service Period (SP) of Restricted Target Wake Time (R-TWT) for the RTA frame exchange. During the R-TWT SPs, the RTA frames have higher priority to transmit than other frames. In the present disclosure, a protocol is described in which an R-TWT scheduling MLD can schedule a Multi-Link (ML) R-TWT with Service Periods (SPs) scheduled on multiple links. These ML R-TWTs can be one or more Single-Link (SL) R-TWTs, and a ML R-TWT can be an independent R-TWT from the SL R-TWT. The R-TWT scheduling MLD can assign a unique ML level R-TWT ID to identify a ML R-TWT. If a ML R-TWT consists of SL R-TWTs, each SL R-TWT is assigned to a unique link level R-TWT ID to identify it on its link. The R-TWT scheduling AP MLD can complete ML R-TWT signaling on one link for the ML R-TWT management on multiple links.

A non-AP MLD sends a ML R-TWT request frame to negotiate its membership of the ML R-TWT. The AP MLD responds with a ML R-TWT response frame to accept or reject the request from the non-AP MLD. The non-AP MLD becomes a member of the ML R-TWT if the AP MLD accepts its request.

A non-AP STA sends a frame containing a ML TWT element for ML R-TWT signaling. The ML TWT element carries one or more Broadcast ML TWT Parameter Set Fields. The ML TWT element contains link information to indicate which links the information in the Broadcast ML TWT Parameter Set Fields is applied to.

Further aspects of the technology described herein will be brought out in the following portions of the specification, wherein the detailed description is for the purpose of fully disclosing preferred embodiments of the technology without placing limitations thereon.

BRIEF DESCRIPTION OF THE DRAWINGS

The technology described herein will be more fully understood by reference to the following drawings which are for illustrative purposes only:

FIG. **1** is an interworking communications diagram of performing Target Wait Time (TWT) in IEEE802.11ax.

FIG. **2** is a data field diagram of a TWT setup frame.

FIG. **3** is a data field diagram of a TWT element defined in IEEE 802.11ax.

FIG. **4** is a data field diagram of a Control field of the TWT element.

FIG. **5** is a data field diagram of a Broadcast TWT Parameter Information field (TWT parameter Information field in TWT element when Negotiation Type is 2 or 3).

FIG. **6** is a data field diagram in the Request type field of the Broadcast TWT parameter Information field of FIG. **5**.

FIG. **7** is a data field diagram of a Broadcast TWT Info field of the Broadcast TWT parameter Information field of FIG. **5**.

FIG. **8** is a communications diagram of a R-TWT SP communication operation in a scenario having AP**1**, STA**1**, STA**2**, and STA**3**.

FIG. **9** is an interworking communications diagram of TWT teardown signaling defined in IEEE 802.11ax.

FIG. **10** is a data field diagram of a TWT Teardown frame.

FIG. **11** through FIG. **13** are data field diagrams of fields of the TWT Flow field.

FIG. **14** is a hardware block diagram of wireless station (STA) hardware according to at least one embodiment of the present disclosure.

FIG. **15** is a hardware block diagram of a station configuration, such as contained in Multi-Link Device (MLD) hardware, according to at least one embodiment of the present disclosure.

FIG. **16** is a station topology diagram for consideration according to at least one embodiment of the present disclosure.

FIG. **17** and FIG. **18** is a flow diagram of an AP affiliated with the R-TWT scheduling AP MLD announcing ML R-TWT scheduling according to at least one embodiment of the present disclosure.

FIG. **19** is a flow diagram of a R-TWT scheduled MLD requesting ML R-TWT membership according to at least one embodiment of the present disclosure.

FIG. **20** is a flow diagram of a R-TWT scheduling an AP MLD responding to a ML R-TWT membership, according to at least one embodiment of the present disclosure.

FIG. **21** is an interworking communications diagram of ML R-TWT membership negotiation signaling according to at least one embodiment of the present disclosure.

FIG. **22** is a flow diagram of a R-TWT scheduling AP MLD tearing down a ML R-TWT according to at least one embodiment of the present disclosure.

FIG. **23** is an interworking communications diagram of ML R-TWT teardown signaling using ML level R-TWT ID, according to at least one embodiment of the present disclosure.

FIG. **24** is a data field diagram of a ML R-TWT setup frame used for membership management of ML R-TWT, according to at least one embodiment of the present disclosure.

FIG. **25** is a data field diagram of a ML R-TWT teardown frame, according to at least one embodiment of the present disclosure.

FIG. **26** is a data field diagram of a ML TWT element according to at least one embodiment of the present disclosure.

FIG. **27** is a data field diagram of the format of the Control field of ML TWT element according to at least one embodiment of the present disclosure.

FIG. **28** is a data field diagram of a Broadcast ML TWT Parameter Set Field, according to at least one embodiment of the present disclosure.

FIG. **29** is a data field diagram of a Request Type field of the Broadcast ML TWT Parameter Set Field, according to at least one embodiment of the present disclosure.

FIG. **30** is a data field diagram of a Request Type field of the Broadcast ML TWT Parameter Set Field, according to at least one embodiment of the present disclosure.

FIG. **31** through FIG. **35** is a data field diagram of the Link Info field according to at least one embodiment of the present disclosure.

FIG. **36** is a communications diagram of R-TWT scheduling with the AP announcing the ML R-TWT SP scheduling on its own link only, according to at least one embodiment of the present disclosure.

FIG. **37** is a communications diagram of a R-TWT scheduling AP announcing SL R-TWT scheduling on all the links, according to at least one embodiment of the present disclosure.

FIG. **38** is a communications diagram of another option for the R-TWT scheduling AP to announce SL R-TWT scheduling on all the links, according to at least one embodiment of the present disclosure.

FIG. **39** is a communications diagram of R-TWT scheduling with AP announcements of ML R-TWT scheduling of SPs on its link, according to at least one embodiment of the present disclosure.

FIG. **40** is a communications diagram of a ML R-TWT setup procedure, according to at least one embodiment of the present disclosure.

FIG. **41** is a communications diagram of a ML R-TWT setup procedure, according to at least one embodiment of the present disclosure.

FIG. **42** is a communications diagram of a ML R-TWT setup procedure over multiple links, according to at least one embodiment of the present disclosure.

FIG. **43** is a communications diagram of a ML R-TWT setup procedure for a ML R-TWT over a link, according to at least one embodiment of the present disclosure.

FIG. **44** is a communications diagram of a ML R-TWT setup procedure for a ML R-TWT, according to at least one embodiment of the present disclosure.

FIG. **45** is a communications diagram of a ML R-TWT setup procedure for a ML R-TWT in which only a partial request is accepted, according to at least one embodiment of the present disclosure.

FIG. **46** is a communications diagram of R-TWT scheduling with an AP announcing the SL R-TWT scheduling and ML R-TWT scheduling in a ML TWT element, according to at least one embodiment of the present disclosure.

FIG. **47** is a communications diagram of a ML R-TWT setup using MLD level R-TWT ID, according to at least one embodiment of the present disclosure.

FIG. **48** is a communications diagram of R-TWT scheduling with the AP announcing all the ML R-TWT scheduling of its affiliated AP MLD, according to at least one embodiment of the present disclosure.

FIG. **49** is a communications diagram of ML R-TWT operations on Special MLD links, according to at least one embodiment of the present disclosure.

DETAILED DESCRIPTION

1. Current Wireless Technologies

1.1. Restricted TWT (R-TWT)

FIG. **1** shows an example of a Target Wait Time (TWT) setup defined in IEEE 802.11ax. The interworking model of the STAs can be the same as defined in the IEEE 802.11 standard.

When the non-AP STA decides to initiate a TWT setup procedure with the AP, then the Station Management Entity (SME) of the non-AP STA sends a MLME-TWTSETUP.request message to its Medium Access Control (MAC) Sublayer Management Entity (MLME). When the MLME of the non-AP STA receives the MLME-TWTSETUP.request message, it collects the information in the MLME-TWTSETUP.request message and sends a TWT setup frame (i.e., TWT request frame) to the AP. The MLME of the AP receives the frame and generates a MLME-TWTSETUP.indication message to its SME.

Then, the SME of the AP sends an MLME-TWTSETUP.response message containing TWT setup result to its MLME. Then, the MLME of the AP sends a TWT setup frame (i.e., TWT response frame) to the non-AP STA. The MLME of the non-AP STA receives the frame and sends an MLME-TWTSETUP.confirm message to its SME. Then, the non-AP can recognize whether the TWT setup has been successful or not.

FIG. **2** depicts the format of a TWT setup frame, having the following fields: Frame Control, Duration, Address (**1-3**), Sequence Control, data, and Frame Check Sequence (FCS). The lower portion of the figure details the subfields within the data field as: Category, Action, Dialog Token and a TWT element which is detailed in FIG. **3**

FIG. **3** depicts the format of TWT element defined in IEEE 802.11ax. The fields are shown as Element ID, Length, Control and TWT Parameter Information. When the negotiation type field in the control field in the TWT element is set to a value of 2 or 3, then the TWT parameter information field in the TWT element carries the broadcast TWT parameter Information field as shown in FIG. **5**.

It should be noted that there is an update in IEEE 802.11be (Draft P802.11be_D1.01) at this time. When the broadcast TWT recommendation field in the Request type field in the Broadcast TWT parameter Information field is set to a value of 4, then this represents the broadcast TWT (B-TWT) indicated in the Broadcast TWT parameter Information field as a restricted TWT (R-TWT).

FIG. **4** depicts the subfields in the Control field of the TWT element seen in FIG. **3**. The subfields are shown as: Neighbor Discovery Protocol (NDP) Paging Indicator, Responder Power-Management (PM) mode, Negotiation type, TWT Information Frame disabled, Wake Duration Unit, and a reserved subfield.

FIG. **5** depicts a Broadcast TWT Parameter Information field (TWT parameter Information field in TWT element when Negotiation Type is 2 or 3).

FIG. **6** depicts the subfields in the Request type field of the Broadcast TWT parameter Information field of FIG. **5**. The subfields are shown as: TWT Request, TWT Setup Command, Trigger, Last Broadcast Parameter Set, Flow Type, Broadcast TWT Recommendation, TWT Wake Interval Exponent, and a Reserved subfield.

FIG. **7** depicts the subfields of the Broadcast TWT Info field of the Broadcast TWT parameter Information field of FIG. **5**. The subfields are shown as: Restricted TWT Traffic Information Present, Reserved, Broadcast TWT ID, and Broadcast TWT Persistence.

According to the definition in IEEE 802.11be, R-TWT elements have the following characteristics. (a) A restricted TWT R-TWT scheduling AP, referred to as an R-TWT scheduling AP, is an Extra High Throughput (EHT) AP that supports restricted TWT operation and sets the Restricted TWT Support subfield in transmitted EHT Capabilities elements to the value of 1. (b) A restricted TWT R-TWT scheduled STA, referred to as an R-TWT scheduled STA, is a non-AP EHT STA that supports restricted TWT operation and sets the Restricted TWT Support subfield in the transmitted EHT Capabilities elements to a value of 1. (c) A R-TWT scheduled STA can establish membership of one or more R-TWTs scheduled by the R-TWT scheduling AP. The R-TWT setup signaling is the same as broadcast TWT with additional parameter settings, which is used for the membership negotiation of a R-TWT between the R-TWT scheduled STA and the R-TWT scheduling AP. After a R-TWT scheduled STA establishes the membership of the R-TWT scheduled by the R-TWT scheduling AP, the R-TWT scheduled STA has higher priority or is allowed to exchange frames with the R-TWT scheduling AP during the SPs of the R-TWT. On the other hand, the R-TWT scheduled STA that is not a member of the R-TWT is either given a lower priority or is not allowed to exchange frames with the R-TWT scheduling AP during the SPs of the R-TWT.

FIG. **8** shows an example of a R-TWT SP communication operation in a scenario having AP**1**, STA**1**, STA**2**, and STA**3**. AP**1** is the R-TWT scheduling AP which announces R-TWT**1** scheduling and manages the members of R-TWT**1**. STA**1** and STA**2** are the member STAs of R-TWT**1**. During the R-TWT**1** SP, AP**1** schedules and prioritizes the frame exchange with the member STAs (e.g., UL PPDU of SCS**1** with STA**1** and DL PPDU of SCS**2** with STA**2**). STAs which can receive (hear) and recognize (understand) the R-TWT scheduling are called R-TWT scheduled STAs. STA**3** is a R-TWT scheduled STA but not a member STA of R-TWT**1**. STA**3** has to end its TXOP before the start time of R-TWT**1** SP. STA**3** can also enter quiet mode or not contend for the channel during R-TWT**1** SP. The scheduling AP can broadcast a quiet element to announce a quiet interval during a R-TWT SP, and the STA hears this element may enter quiet mode.

FIG. **9** shows the TWT teardown signaling defined in IEEE 802.11ax. The interworking model of the STAs can be the same as defined in IEEE 802.11ax standard.

The AP decides to teardown a TWT and performs the following. The Station Management Entity (SME) of the AP sends a MLME-TWTTEARDOWN.request message to its MAC Sublayer Management Entity (MLME). When the MLME of the AP receives the MLME-TWTTEARDOWN.request message, it collects the information in the MLME-TWTTEARDOWN.request message and sends (e.g., unicast, groupcast, or broadcast) a TWT teardown frame to the non-AP STAs. The MLME of the non-AP STA receives the frame and generates a MLME-TWTTEARDOWN.indication message carrying the information in the frame to its SME. Then, the SME of the non-AP STA sends an MLME-TWTTEARDOWN.indication message to its MLME. Then, the MLME of the non-AP STA knows which TWT(s) is teared down by the AP.

FIG. **10** depicts the format of TWT Teardown frame, having fields: Frame Control, Duration, Address (**1-3**), Sequence Control, data and FCS. The data field is shown here having subfields of Category, Action and TWT Flow.

FIG. **11** through FIG. **13** depict fields of the TWT Flow field as was seen in FIG. **10**. A type 0 or 1 TWT Flow field format is seen in FIG. **11** having the subfields of: TWT Flow Identifier, Reserved, Negotiation Type, and Teardown All TWT. A type 2 TWT Flow field format is seen in FIG. **12** having the subfields of: Reserved, Negotiation Type, and Reserved. A type 3 TWT Flow field is seen in FIG. **13** indicating the teardown of a broadcast TWT whose ID is indicated in the Broadcast TWT ID field. If the Broadcast TWT ID field is referred to a R-TWT, then this field indicates the teardown of a R-TWT. This field also contains a Negotiation Type, and Teardown All TWT subfields.

2. Problem Statement

The current wireless communication systems use EDCA and R-TWT to prioritize the RTA traffic transmission. During the R-TWT SP, the RTA traffic is prioritized to transmit. Meanwhile, the current wireless communication systems define a multiple-link device (MLD) which affiliates with one or more STAs whereby each STA operates on a different link. R-TWT SPs can be scheduled on multiple links to provides improved quality of service, such as throughput, latency, reliability, and jitter, for the RTA traffic transmission. However, the current R-TWT is managed and operated at the link level only. There is no mechanism to manage and schedule R-TWTs from the view of MLD. The R-TWT is scheduled on each link separately which can result in significantly large overhead due to the signaling for R-TWT

management. Also, the coordination of the R-TWTs on different links is not feasible in view of link level management considerations.

3. Contribution of the Present Disclosure

By utilizing the proposed technologies, the R-TWT scheduling MLD can schedule a Multi-Link (ML) R-TWT whose SPs are scheduled on multiple links. A ML R-TWT can consist of one or more Single-Link (SL) R-TWTs as described in Section 1.1, whose SPs are scheduled on the same link. Alternatively, a ML R-TWT can be an independent R-TWT from the SL R-TWT.

By utilizing the protocol of the present disclosure, the R-TWT scheduling MLD can assign a unique ML level R-TWT ID to identify a ML R-TWT. If a ML R-TWT consists of SL R-TWTs, each SL R-TWT is assigned to a unique link level R-TWT ID to identify it on its link.

By utilizing the protocol of the present disclosure, the R-TWT scheduling AP MLD can complete (finish) the ML R-TWT signaling on one link for the ML R-TWT management on multiple links.

4. Embodiment

4.1. Communication Station (STA and MLD) Hardware

FIG. **14** illustrates an example embodiment **10** of STA hardware configured for executing the protocol of the present disclosure. An external I/O connection **14** preferably couples to an internal bus **16** of circuitry **12** upon which are connected a CPU **18** and memory (e.g., RAM) **20** for executing a program(s) which implement the communication protocol. The host machine accommodates at least one modem **22** to support communications coupled to at least one RF module **24**, **28** each connected to one or multiple antennas **29**, **26***a*, **26***b*, **26***c* through **26***n*. An RF module with multiple antennas (e.g., antenna array) allows for performing beamforming during transmission and reception. In this way, the STA can transmit signals using multiple sets of beam patterns.

Bus **14** allows connecting various devices to the CPU, such as to sensors, actuators and so forth. Instructions from memory **20** are executed on processor **18** to execute a program which implements the communications protocol, which is executed to allow the STA to perform the functions of an access point (AP) station or a regular station (non-AP STA). It should also be appreciated that the programming is configured to operate in different modes (TXOP holder, TXOP share participant, source, intermediate, destination, first AP, other AP, stations associated with the first AP, stations associated with other AP, coordinator, coordinatee, AP in an OBSS, STA in an OBSS, and so forth), depending on what role it is performing in the current communication context.

Thus, the STA HW is shown configured with at least one modem, and associated RF circuitry for providing communication on at least one band. The present disclosure is primarily directed at the sub 6 GHz band.

It should be appreciated that the present disclosure can be configured with multiple modems **22**, with each modem coupled to an arbitrary number of RF circuits. In general, using a larger number of RF circuits will result in broader coverage of the antenna beam direction. It should be appreciated that the number of RF circuits and number of antennas being utilized is determined by hardware constraints of a specific device. A portion of the RF circuitry and antennas may be disabled when the STA determines it is unnecessary to communicate with neighboring STAs. In at least one embodiment, the RF circuitry includes frequency converter, array antenna controller, and so forth, and is connected to multiple antennas which are controlled to perform beamforming for transmission and reception. In this way the STA can transmit signals using multiple sets of beam patterns, each beam pattern direction being considered as an antenna sector.

In addition, it will be noted that multiple instances of the station hardware as shown in the figure, can be combined into a multi-link device (MLD), which typically will have a processor and memory for coordinating the activity, while there is not always a need for a separate CPU and memory for each STA within the MLD.

FIG. **15** illustrates an example embodiment **40** of a Multi-Link Device (MLD) hardware configuration. Soft AP MLD is a MLD that consists of one or more affiliated STAs, which are operated as APs. Soft AP MLD should support multiple radio operation on 2.4 GHz, 5 GHz and 6 GHz. Among multiple radios, basic link sets are the link pairs that satisfy simultaneous transmission and reception (STR) mode, e.g., basic link set (2.4 GHz and 5 GHz), basic link set (2.4 GHz and 6 GHz).

The conditional link is a link that forms a non-simultaneous transmission and reception (NSTR) link pair with some basic link(s). For example, these link pairs may comprise a 6 GHz link as the conditional link corresponding to 5 GHz link when 5 GHz is a basic link; 5 GHz link is the conditional link corresponding to 6 GHz link when 6 GHz is a basic link. The soft AP is used in different scenarios including Wi-Fi hotspots and tethering.

Multiple STAs are affiliated with an MLD, with each STA operating on a link of a different frequency. The MLD has external I/O access to applications, this access connects to a MLD management entity **48** having a CPU **62** and memory (e.g., RAM) **64** to allow executing a program(s) that implement communication protocols at the MLD level. The MLD can distribute tasks to, and collect information from, each affiliated station to which it is connected, exemplified here as STA **1** **42**, STA **2** **44** through to STA N **46** and the sharing of information between affiliated STAs.

In at least one embodiment, each STA of the MLD has its own CPU **50** and memory (RAM) **52**, which are coupled through a bus **58** to at least one modem **54** which is connected to at least one RF circuit **56** which has one or more antennas. In the present example the RF circuit has multiple antennas **60***a*, **60***b*, **60***c* through **60***n*, such as in an antenna array. The modem in combination with the RF circuit and associated antenna(s) transmits/receives data frames with neighboring STAs. In at least one implementation the RF module includes frequency converter, array antenna controller, and other circuits for interfacing with its antennas.

It should be appreciated that each STA of the MLD does not necessarily require its own processor and memory, as the STAs may share resources with one another and/or with the MLD management entity, depending on the specific MLD implementation. It should be appreciated that the above MLD diagram is given by way of example and not limitation, whereas the present disclosure can operate with a wide range of MLD implementations.

4.2. Network Topology for Consideration

FIG. **16** illustrates an example STA topology **65** for consideration in the examples of the present disclosure. The figure is provided to aid in the discussions of the techniques involved and toward engendering an improved understanding of the proposed technology. It should be appreciated that

the present disclosure is in no way limited to the topology of this example, as the protocol may be utilized on communications between WLAN STAs and MLDs of any desired topology.

A MLD is a device that has more than one affiliated STA and has one MAC service access point (SAP) to logical link control (LLC), which includes one MAC data service.

An MLD is an AP MLD, if APs are affiliated with that MLD. An MLD is a non-AP MLD, if non-AP STAs are affiliated with that MLD.

As shown in FIG. **16** the scenario is exemplified as having three MLDs **70**, **72** and **74**. AP**1** **76** and AP**2** **78** are affiliated with multi-link device **70** (MLD) #**1**, STA**1** **80** and STA**4** **86** are affiliated with MLD #**2** **72**, and STA**3** **84** and STA**5** **88** are affiliated with MLD#**3** **74**. STA**2** **84** is a R-TWT scheduled station which may comprise a non-AP STA operating on Link**1**, or a single link MLD (i.e., a special MLD which only has one STA and operates on one link). STA**6** **92** is not a R-TWT scheduled station, and this station may also comprise a non-AP STA operating on Link**1**, or a single link MLD (i.e., a special MLD which only has one STA and operates on one link).

As shown in the figure this scenario assumes there are three MLDs, two APs, and six STAs in a given area, depicted here as meeting room **94**, shown with aperture(s) (e.g., doors, windows and so forth) **96**. STA**1**, STA**2**, STA**3**, and STA**6** are associated with AP**1** over Link**1** and STA**4** and STA**5** are associated with AP**2** over Link**2**.

All STAs use EDCA for random channel access on all the links. A R-TWT scheduling AP is able to schedule and announce R-TWTs. A R-TWT scheduled STA is the non-AP STA that is able to receive and recognize the R-TWT announcement from the R-TWT scheduling AP and support the R-TWT operations. A R-TWT scheduled STA is able to negotiate membership of a R-TWT with the R-TWT scheduling AP. When a R-TWT scheduled STA becomes a member STA of a R-TWT, the traffic (e.g., UL, DL, P2P) of the R-TWT scheduled STA (i.e., the R-TWT member STA) is scheduled and prioritized to transmit during the SPs of that R-TWT.

AP**1** and AP**2** are the R-TWT scheduling APs. STA**1** through STA**5** are R-TWT scheduled STAs; while STA**6** is not a R-TWT scheduled STA.

4.3. Definitions of ML R-TWT

This introduces the definitions used in this disclosure. An AP MLD which supports ML R-TWT operation is denoted as a R-TWT scheduling AP MLD. A non-AP MLD which supports ML R-TWT operation is denoted as a R-TWT scheduled MLD. After a R-TWT scheduled MLD negotiates ML R-TWT setup with the R-TWT scheduling AP MLD successfully, the R-TWT scheduled MLD becomes a member MLD of that R-TWT. Then, the traffic of the member MLD will be prioritized to transmit during the SPs of that R-TWT. For example, as shown in FIG. **16**, MLD**1** is the R-TWT scheduling AP MLD. MLD**2** and MLD**3** are the R-TWT scheduled MLDs.

A SL R-TWT is scheduled by a R-TWT scheduling AP and its SPs are scheduled on the same link of the R-TWT scheduling AP, which is the same as defined in Section 1.1. The R-TWT scheduling AP assigns a unique ID, denoted as link level R-TWT ID, to the SL R-TWT. A link level R-TWT ID can be used to identify a SL R-TWT by the R-TWT scheduling AP and its affiliated STA on their own link.

A ML R-TWT is scheduled by the R-TWT scheduling MLD and its SPs are scheduled on one or more links. An ML R-TWT consists of one or more SL R-TWTs scheduled by the different APs affiliated with a same R-TWT scheduling AP MLD. The SPs of the ML R-TWT are the SPs of those SL R-TWTs. A ML R-TWT can be either an implicit ML R-TWT or an explicit ML R-TWT.

An explicit ML R-TWT is an ML R-TWT which is assigned to a unique ID, denoted as MLD level R-TWT ID, by the R-TWT scheduling AP MLD over all its links (or more than one link). A MLD level R-TWT ID can be used to identify a ML R-TWT by the R-TWT scheduling AP MLD and its affiliated MLDs on all their links.

An implicit ML R-TWT is not assigned to a unique MLD level R-TWT ID by the R-TWT scheduling AP MLD. An implicit ML R-TWT can be a group of SL R-TWTs which share at least one of the following in common. (a) The SL R-TWTs have the same link level R-TWT ID but are scheduled on different links. (b) The SL R-TWTs have the same SP scheduling on different links. (c) The SL R-TWTs whose scheduling is announced in the same ML TWT element.

It should be noted that the implicit ML R-TWT is not the implicit TWT (individual TWT) as defined in IEEE 802.11.

When a ML R-TWT consists of one SL R-TWT only, it is the same as a SL R-TWT.

In some instances, a R-TWT scheduled MLD can become a member MLD of an ML R-TWT on some of the links where the ML R-TWT SPs are scheduled. Then, the traffic of the member MLD is prioritized to transmit only on those links, but not all the links of ML R-TWT SPs, during ML R-TWT SPs. For example, a ML R-TWT schedules its SPs on link**1**, link**2**, and link**3**. A R-TWT scheduled MLD becomes a member MLD of that ML R-TWT only on link**1** and link**2**. Then, the traffic of the R-TWT scheduled MLD is prioritized to transmit on link**1** and link**2** during ML R-TWT SPs.

The operation of the R-TWT scheduling AP and R-TWT scheduled STA for the ML R-TWT SPs on each link can be the same as R-TWT operation defined in IEEE 802.11be. For example, a R-TWT scheduled STA shall end its TXOP before the start of a ML R-TWT SP scheduled on its link.

In at least one embodiment/mode/option the SP scheduling (such as SP start time, SP duration, interval between SPs and so on) of a ML R-TWT on different links has to be the same.

4.4. ML R-TWT Signaling

This section explains the ML R-TWT signaling for ML R-TWT scheduling announcement, ML R-TWT membership negotiation, and ML R-TWT teardown. The purpose of ML R-TWT signaling is to let the signaling transmitted over one link manage the ML R-TWTs.

If all the R-TWT scheduled MLDs are operating (or enabled) on the same link, then the R-TWT scheduling AP may only launch a signal sequence (such as trigger frame+ PS-Poll in B-TWT SP) on that link to indicate the start of the ML R-TWT SPs on multiple links.

The R-TWT scheduling AP may only send a signal (such as a broadcast EOSP signal) on that link to indicate the end of the ML R-TWT SPs on multiple links. The R-TWT scheduling AP may announce ML R-TWT scheduling through sending a beacon on that link only.

If a R-TWT scheduled MLD requests the membership of a ML R-TWT for the transmission of a traffic stream under a Traffic Specification (TSPEC) or a QoS Characteristics element during the ML R-TWT SPs, then the AP considers whether it can satisfy the QoS requirements of the traffic stream based on the capacity of all the links where the ML R-TWT SPs are scheduled. It should be noted that for a SL R-TWT membership negotiation, the AP may only consider

whether it can satisfy QoS requirements of the traffic stream based on the capacity of the link where the SL R-TWT SPs are scheduled.

The traffic transmitted during ML R-TWT SPs may be subject to the TID-to-Link mapping between the non-AP MLD and AP MLD. For SPs of a ML R-TWT on multiple links, it is possible that all those links shall have the same TID to link mapping during ML R-TWT SP, or each link shall have at least one TID of latency sensitive traffic that can be mapped to the link during ML R-TWT SP.

It should be noted that the ML R-TWT signaling as described in this disclosure can also be used for the broadcast TWT signaling when the broadcast TWT recommendation field in the Request type field in Broadcast ML TWT parameter Information field is set to a value of "2" or "3".

4.4.1. Announcement of ML R-TWT Scheduling

FIG. **17** and FIG. **18** illustrate an example embodiment **110** of an AP affiliated with R-TWT scheduling AP MLD announcing the ML R-TWT scheduling. When the AP is to send **112** a frame to announce the ML R-TWT scheduling, it can have multiple options as determined at block **114**.

If the AP selects Option**1**, then at block **116** of FIG. **18** the AP adds ML TWT element(s) carrying the Broadcast ML TWT parameter set field(s) to the frame to announce the scheduling of the ML R-TWTs that has SPs scheduled on the link of the AP and their concurrent SPs on other links. Examples of Option **1** are shown in FIG. **39** and FIG. **40**.

If at block **114** in FIG. **17**, the AP chooses Option **2**, then at block **120** in FIG. **18** the AP adds ML TWT element(s) carrying the Broadcast ML TWT parameter set field(s) to the frame to announce the scheduling of the ML R-TWT SPs on its own link only. For example, for a ML R-TWT whose SPs are scheduled on link**1** and link**2**, the AP on link**1** only announces the SP scheduling of the ML R-TWT on link**1** in its frame, and the AP on link**2** only announces the SP scheduling of the ML R-TWT on link**2** in its frame. An example is shown in FIG. **36**.

If at block **114** in FIG. **17**, the AP chooses Option **3**, then at block **122** in FIG. **18** the AP adds ML TWT element(s) carrying the Broadcast ML TWT parameter set field(s) to the frame to announce the scheduling of all the ML R-TWTs scheduled by the R-TWT scheduling AP MLD. Examples of this case are depicted in FIG. **37**, FIG. **38**, FIG. **46**, and FIG. **48**.

Then, in each of these cases the AP sends **118** of FIG. **18** (e.g., unicasts, multicasts, groupcasts, or broadcasts) the frame to its associated non-AP STAs.

The frame which carries the information of ML R-TWT scheduling can be a beacon frame, (ML) probe response frame, (re)association response frame or other management frames.

It is possible that the ML TWT element is contained in Multiple BSSID elements as defined in IEEE 802.11 to announce the ML R-TWT scheduling of the R-TWT MLD of the corresponding non-transmitted BSS.

The format of ML TWT element and Broadcast ML TWT parameter set field are shown in Section 4.5.

4.4.2. Negotiation of ML R-TWT Membership

This section shows the flowcharts of ML R-TWT membership negotiation from the R-TWT scheduled MLD side and the R-TWT scheduling AP MLD side.

FIG. **19** illustrates an example embodiment **130** of a R-TWT scheduled MLD requesting ML R-TWT membership. A R-TWT scheduled MLD is to negotiate **132** with the R-TWT scheduling AP MLD over a link, for example link**1**, about its membership of a ML R-TWT scheduled by the R-TWT scheduling AP MLD.

Then, the STA affiliated with the R-TWT scheduled MLD on link**1** sends **134** a ML R-TWT request frame carrying the broadcast ML TWT parameter set fields of that ML R-TWT in ML TWT element over link**1**.

A check **136** determines if the R-TWT scheduled MLD receives the ML TWT response frame which indicates that the R-TWT scheduling AP accepts the membership request of the ML R-TWT. If this condition is met, then the R-TWT scheduled MLD is a member **138** of the ML R-TWT.

Otherwise, if this condition is not met, then the R-TWT scheduled MLD is not a member **140** of the ML R-TWT.

It should be noted that it is possible that the ML R-TWT request frame and the ML TWT response frame are to be transmitted over different links. An example is shown in FIG. **42**. The format of the ML R-TWT request frame and the ML TWT response frame are shown in FIG. **24**.

When the R-TWT scheduled MLD requests ML R-TWT whose SPs are scheduled on multiple links, in at least one embodiment/mode/option the R-TWT scheduling AP MLD can respond that the R-TWT scheduled MLD is to be member of the ML R-TWT on partial links where the ML R-TWT SPs are scheduled. For example, if the ML R-TWT consists of multiple SL R-TWTs, then the ML R-TWT scheduled MLD can become a member of some of the SL R-TWTs, while not be allowed as a member of the other SL R-TWTs. Then, the ML R-TWT scheduled MLD may request membership of the other SL R-TWTs of which it is not a member independently. In at least one other embodiment/mode/option the R-TWT scheduling AP MLD can be configured to either accept the membership of ML R-TWT SPs on all the links where the ML R-TWT SPs are scheduled, or not to allow membership on any of those links.

FIG. **20** illustrates an example embodiment **150** of a R-TWT scheduling AP MLD responding to a ML R-TWT membership. The R-TWT scheduling AP MLD receives **152** a ML R-TWT request frame over a link, such as link**1**, from a R-TWT scheduled MLD to negotiate its membership of a ML R-TWT.

Then, the R-TWT scheduling AP MLD sends **154** a ML R-TWT response frame carrying the broadcast ML TWT parameter set fields of that ML R-TWT to indicate the decision of membership negotiation of that ML R-TWT on either link**1** or another link.

In at least one embodiment/mode/option the R-TWT scheduling AP MLD has to send a ML R-TWT response frame on the same link as the ML R-TWT request frame was sent over (e.g., link**1** in this example). The format of the ML R-TWT request frame and the ML TWT response frame are shown in FIG. **24**.

FIG. **21** illustrates an example embodiment **170** of ML R-TWT membership negotiation signaling (i.e., setup procedure) between the R-TWT scheduled MLD (non-AP MLD) and the R-TWT scheduling AP MLD (AP MLD). The figure depicts communications between a non-AP MLD Station Management Entity (SME) **172** and its MLD/STA MAC Layer Management Entity (MLME) **174**, and over the network with an AP MLD/AP MLME **176** and its AP SME **178**. The interworking model of the STAs can be the same as that defined in IEEE 802.11be standard.

The non-AP MLD decides (determines) to initiate a ML R-TWT setup procedure with the AP MLD. The Station Management Entity (SME) of the non-AP MLD sends a MLME-TWTSETUP.request message **180** to its MAC Sublayer Management Entity (MLME). When the MLME of the non-AP MLD/STA receives the MLME-TWTSETUP.request message, it collects the information in the MLME-TWTSETUP.request message and sends a ML R-TWT setup

frame **182** (i.e., ML R-TWT request frame) to the AP MLD. The MLME of the AP or the AP MLD receives the frame and generates a MLME-TWTSETUP.indication message **184** to its SME.

Then, the SME of the AP MLD processes **186** this request information and sends an MLME-TWTSETUP.response message **188** containing ML R-TWT setup results to its MLME. Then, the MLME of the AP or the AP MLD sends a ML R-TWT setup frame **190** (i.e., ML R-TWT response frame) to the non-AP MLD. The MLME of the non-AP MLD or STA receives the frame and sends an MLME-TWTSETUP.confirm message **192** to its SME. Then, the non-AP MLD can determine (know) whether the ML R-TWT setup was successful or not. The format of ML R-TWT setup frame is shown in FIG. **24**.

In at least one embodiment/mode/option the AP MLD can send an unsolicited ML R-TWT response frame to the non-AP MLD to establish, modify, or terminate the ML R-TWT membership of the non-AP MLD.

4.4.3. Teardown of ML R-TWT

FIG. **22** illustrates an example embodiment **210** of a R-TWT scheduling AP MLD tearing down a ML R-TWT. The AP determines **212** either of multiple options, here indicated as Option **1** and Option **2**, for tearing down the ML R-TWT.

If at block **212** Option **1** is selected, then at block **214** the R-TWT scheduling AP MLD tears down a ML R-TWT using ML level R-TWT ID. In this case, the R-TWT scheduling AP MLD sends **216** a ML R-TWT teardown frame to indicate the ML level R-TWT ID it plans to tear down. The format of ML R-TWT teardown frame can be as that shown in FIG. **25**.

If at block **212** Option **2** is selected, then at block **218** then the R-TWT scheduling AP MLD tears down a SL R-TWT of a ML R-TWT using SL level R-TWT ID. Then, the R-TWT scheduling AP MLD sends **220** a TWT teardown frame carrying TWT Flow field with Negotiation Type subfield=3 on the link where the SPs of that SL R-TWT are scheduled. It should be noted that the other SL R-TWTs of the ML R-TWT is not torn down in this case. The format of TWT teardown frame can be the same as shown in FIG. **10**, but is not limited thereto.

FIG. **23** illustrates an example embodiment **230** of ML R-TWT teardown signaling using ML level R-TWT ID. The interworking model of the STAs can be the same as defined in IEEE 802.11be standard. In FIG. **23**, as in FIG. **21**, are depicted communications between a non-AP MLD Station Management Entity (SME) **172** and its MLD/STA MAC Layer Management Entity (MLME) **174**, and over the network with an AP MLD/AP MLME **176** and its AP SME **178**.

The AP MLD has determined (decided) **232** to teardown a ML R-TWT. The Station Management Entity (SME) of the AP MLD sends a MLME-TWTTEARDOWN.request message **234** to its MAC Sublayer Management Entity (MLME) or the MLME of its affiliated AP. When the MLME of the AP or the AP MLD receives the MLME-TWTTEARDOWN-.request message, it collects the information in the MLME-TWTTEARDOWN.request message and sends (unicast, groupcast, or broadcast) a ML R-TWT teardown frame **236** to the non-AP MLD. The MLME of the non-AP MLD or STA receives the frame and generates a MLME-TWTTEARDOWN.indication message carrying the information in the frame to its SME.

Then, the SME of the non-AP MLD sends **238** an MLME-TWTTEARDOWN.indication message to its MLME or the MLME of its affiliated AP. Then, the MLME of the non-AP MLD or STA can recognize (know) which TWT(s) have been torn down by the AP. The format of TWT teardown frame is shown in FIG. **25**.

4.5. Frame Formats

This section shows the format of ML R-TWT setup frame and ML R-TWT Teardown frame.

4.5.1. ML R-TWT Setup Frame

FIG. **24** illustrates an example embodiment **310** of a ML R-TWT setup frame used for membership management of ML R-TWT.

When a ML R-TWT setup frame is sent to request a membership of ML R-TWT, it is a ML R-TWT request frame. When a ML R-TWT setup frame is sent in response to a membership request of ML R-TWT, it is a ML R-TWT response frame. It should be noted that in at least one embodiment/mode/option the R-TWT scheduling AP MLD can send an unsolicited ML R-TWT response frame to the non-AP MLD to establish, modify, or terminate the ML R-TWT membership of the non-AP MLD.

The ML R-TWT setup frame has the following fields. The Frame Control field indicates the type of frame. Duration field contains Network Allocation Vector (NAV) information used for CSMA/CA channel access. The Address**1** field contains address for the recipient of the frame. The Address**2** field contains the address of the STA that transmitted the frame. The Address**3** field contains the BSSID for the recipient. The Sequence control field contains the fragment number and the sequence number of the frame.

The data field is shown with the following subfields. The Category and Action subfields are set to indicate the frame is a ML R-TWT setup frame. In at least one embodiment/mode/option the Category field and the Action field can be set to the same values of the TWT setup frame as shown in FIG. **2**.

The Dialog token subfield is used for matching the ML R-TWT response frame with the ML R-TWT request frame when there are multiple concurrent ML R-TWT membership negotiations. For a ML R-TWT membership negotiation, the ML R-TWT response frame and the ML R-TWT request frame should share the same unique dialog token number. If the ML R-TWT response frame and the ML R-TWT request frame are sent over different links, their dialog tokens should be unique over all the links between the non-AP MLD which sends the ML R-TWT request frame and the AP MLD which sends the ML R-TWT response frame.

The ML TWT element is set to indicate the ML R-TWT membership negotiation or management information. The format of the ML TWT element is shown in FIG. **26**.

4.5.2. ML R-TWT Teardown Frame

FIG. **25** illustrates an example embodiment **330** of a ML R-TWT teardown frame, having the following fields. The Frame Control field indicates the type of the frame. The Duration field contains NAV information used for CSMA/CA channel access. The Address**1** field contains an address for the recipient of the frame. The Address**2** field contains the address of the STA that transmitted the frame. The Address**3** field contains the BSSID for the receiver. The Sequence control field contains the fragment number and the sequence number of the frame.

The data field is shown with the following subfields. The Category and Action subfield are set to indicate the frame is a ML R-TWT teardown action frame. It is possible that the Category subfield and the Action subfield are set to the same numbers of the TWT teardown frame as shown in FIG. **10**.

The TWT Flow subfield is set to indicate which ML R-TWT is torn down by the R-TWT scheduling AP MLD. When the receiver, i.e., the R-TWT scheduled MLD,

receives this subfield, it can recognize (know) which ML R-TWT has been torn down. Accordingly, it should not request membership of that ML R-TWT. If the receiver is already a member of that ML R-TWT, it should quit its membership immediately after receiving this subfield. If the ML R-TWT consists of multiple SL R-TWTs, it is possible that when the ML R-TWT is torn down, its SL R-TWTs are also torn down. Alternatively, in at least one embodiment/mode/option when the ML R-TWT is torn down, its associated SL R-TWTs are not necessarily torn down.

The subfields of the TWT flow subfield are as follows. The ML R-TWT ID subfield is set to indicate which ML R-TWT has been torn down by the R-TWT scheduling AP MLD. This subfield can be reserved when the Teardown All ML R-TWT field is set to "1".

The Negotiation Type subfield is set to indicate that the content in the TWT flow field is for ML R-TWT teardown, such as the existence of ML R-TWT field and Teardown All ML R-TWT field. For example, the negotiation type can be set to a value of 2.

The Teardown All ML R-TWT subfield is set to indicate whether the R-TWT scheduling MLD tears down all its ML R-TWTs. This subfield can be implemented as one bit indication, as exemplified here. When this subfield is set to a first state (e.g., "1"), this indicates that the R-TWT scheduling MLD tears down all its ML R-TWTs. Otherwise, it is set to a second state (e.g., "0") indicating that the R-TWT scheduling MLD only tears down the ML R-TWT indicated in the ML R-TWT ID field.

4.6. ML TWT Element Format

This section illustrates the format of ML TWT element. The ML TWT element is set to indicate the ML R-TWT membership negotiation or management information.

If the ML TWT element is sent in a ML R-TWT request frame, then the ML TWT element is set to indicate the requirement of the ML R-TWT membership of the transmitter. When the recipient receives this element, it makes a determination of whether to accept the membership request based on the requirements of the ML R-TWT membership request. Then, the receiver sends a ML R-TWT response frame to indicate its decision on the membership request.

If the ML TWT element is sent in a ML R-TWT response frame, then the ML TWT element is set to indicate the decision of the ML R-TWT membership request.

If the ML R-TWT membership request is accepted, the ML TWT element also carries the ML R-TWT SP scheduling for its member. When the receiver, such as the R-TWT scheduled MLD, receives this field, it recognizes that its ML R-TWT membership request has been accepted, and it becomes a member of the ML R-TWT, and operates following ML R-TWT SP scheduling.

If ML R-TWT membership request is rejected, then the receiver recognizes that it is not a member of the ML R-TWT. Additionally, the ML TWT element may carry the suggested parameters that the receiver can use to re-request the ML R-TWT member.

If the ML TWT element is sent in a ML R-TWT scheduling announcement frame, such as a beacon, then this field is set to indicate the ML R-TWT scheduling of the ML R-TWT scheduling AP MLD. The recipient receiving this element can determine the ML R-TWT scheduling of the ML R-TWT scheduling AP MLD. If the receiver is a R-TWT scheduled MLD, it operates following the ML R-TWT scheduling. It can also request membership of the ML R-TWTs that are announced by the ML R-TWT scheduling AP MLD.

There also may exist multiple ML TWT elements in the same ML R-TWT setup frame or in the same ML R-TWT scheduling announcement frame.

FIG. **26** illustrates an example embodiment **350** of a ML TWT element, having the following fields. An Element ID field is set to indicate that the element is an ML TWT element. This field can be set to the same value as the TWT element as shown in FIG. **3**. A Length field is set to indicate the length of the element. A Control field is included whose subfields are described below in FIG. **27**. A TWT Parameter Information field is included which may have multiple Broadcast ML TWT Parameter Set field, whose subfields are described in FIG. **28**.

If the Broadcast ML TWT Parameter Set Field is used for the scheduling announcement, then it indicates the ML R-TWT scheduling. The receiver, such as R-TWT scheduled MLD, can operate following the ML R-TWT scheduling and request membership of the ML R-TWT.

If a Broadcast ML TWT Parameter Set Field is used by the R-TWT scheduled MLD to send a ML R-TWT membership request, then it is set to indicate its requirement of the ML R-TWT. When the ML R-TWT scheduling AP MLD receives the request, it decides to accept or reject the request based on the requirement of the R-TWT scheduled MLD.

If a Broadcast ML TWT Parameter Set Field is used by the R-TWT scheduling MLD to accept a membership request from a R-TWT scheduled MLD, then it is set to indicate the ML R-TWT scheduling of which the R-TWT scheduled MLD becomes the member. After the R-TWT scheduled MLD receives this field, it becomes the member of the ML R-TWT. The traffic of the R-TWT scheduled MLD will be prioritized to transmit during the SPs of the ML R-TWT.

If the Broadcast ML TWT Parameter Set Field is used by the R-TWT scheduling MLD to reject (e.g., the TWT setup command field is set to "Reject TWT") a membership request from a R-TWT scheduled MLD, then the R-TWT scheduled MLD recognizes that its membership request has been rejected or its existing ML R-TWT membership is terminated by the R-TWT scheduling MLD after it receives the field.

If the Broadcast ML TWT Parameter Set Field is used by the R-TWT scheduling MLD to reject (e.g., the TWT setup command field is set to "Alternate TWT" or "Dictate TWT") a membership request from a R-TWT scheduled MLD, then it is set to indicate the suggested parameters that the R-TWT scheduled MLD can use to request the ML R-TWT membership for the next time. When the R-TWT scheduled MLD receives this field, it recognizes that it has not obtained membership for the ML R-TWT, but can use the suggested parameters to re-request ML R-TWT membership.

Each Broadcast ML TWT Parameter Set Field can represent the parameter setting of either multiple (including one) SL R-TWTs or one ML R-TWT. The following are provided by way of example. (a) One Broadcast ML TWT Parameter Set Field can represent a ML R-TWT with a MLD level R-TWT ID. (b) One broadcast ML TWT Parameter Set Field can represent one or more SL R-TWTs with the same parameter setting and the same SL level R-TWT ID, but scheduled on different links. The SL R-TWTs in the same broadcast ML TWT Parameter Set Field may belong to a same ML R-TWT.

FIG. **27** illustrates an example embodiment **370** of the Control field of ML TWT element shown in FIG. **26**. The fields NDP Paging Indicator, Responder PM Mode, Negotiation Type, TWT Information Frame Disabled, and Wake Duration Unit field can be identical to those in the control field of the TWT element as shown in FIG. **4**.

The ML TWT Indication field is set to indicate whether the TWT Parameter Information field in the ML TWT element carries the Broadcast ML TWT Parameter Set Field. This field may be implemented as a one bit indication. For example, when this field is set to a first state (e.g., "1"), then the ML TWT element carries the Broadcast ML TWT Parameter Set Field only. Otherwise, this field is set to a second state (e.g., "0") and the ML TWT element carries the Broadcast TWT Parameter Set Field only. It should be noted that if the element ID of the ML TWT element is the same as in the TWT element, then this field can also be used to indicate whether the element is a TWT element or a ML TWT element. If this field is set to a first state (e.g., "1"), then the element is a ML TWT element; otherwise, if this field set to a second state (e.g., "0") then it is a TWT element.

A Link Info Present field is set to indicate the presence of the link info field. If this field is set to a first state (e.g., "1"), then the link info field is presented in the control field. If this field is set to a second state (e.g., "0"), then the link info field is not presented in the control field.

A Link Info field is set to indicate which links the content to which the ML TWT element applies (i.e., which links the content of all the broadcast ML TWT Parameter Set fields in the ML TWT element are applied to). When the receiver, e.g., an MLD, receives this field it has information on which links the content of the ML TWT element is applied to and forwards those parameters to its affiliated STAs operating on those links. For example, if an MLD receives a ML TWT element on link**1** and the Link Info field in the Control Field is set to link**2**, then the ML TWT element is for the R-TWT SP scheduled on link**2**. The MLD may forward the Broadcast ML TWT Parameter Set Field to its affiliated STA on link**2**. The format of the Link Info field can be one of the figures between FIG. **31** through FIG. **35**.

It should be noted that the Link Info field in the Control field as shown in FIG. **27** and Link Info field in the Broadcast ML TWT Parameter Set Field as shown in FIG. **28** cannot be present in the same ML TWT element at the same time.

If the Link Info field is not present in both the Control field and the Broadcast ML TWT Parameter Set Field, then the Broadcast ML TWT Parameter Set Field is for a SL R-TWT on the link where the Broadcast ML TWT Parameter Set Field is transmitted.

FIG. **28** illustrates an example embodiment **390** of a Broadcast ML TWT Parameter Set Field. Each Broadcast ML TWT Parameter Set Field can represent the parameter setting for one or more SL R-TWTs (with the same link level ID but scheduled on different links) which belong to a ML R-TWT. A Request Type field can be set as shown in FIG. **29**.

A Target Wake Time field is set to indicate the start time of the R-TWT SP. If this field is set for the scheduling announcement, then this field indicates the start time of the first SP of the R-TWT after the scheduling announcement frame (e.g., beacon). The R-TWT scheduled MLD will have start time information for the first SP of the R-TWT after receiving this field. If this field is set for the ML R-TWT membership request of the R-TWT scheduled MLD, then this field indicates the start time of the first SP of the R-TWT if the R-TWT scheduled MLD becomes the member of the R-TWT. The R-TWT scheduling MLD can decide whether to accept the membership request according to this field. If this field is set for the ML R-TWT response when the TWT setup command field is set to "Alternate TWT" or "Dictate TWT", then this field indicates the suggested parameter that the R-TWT scheduled MLD can use to set this field when it decides to request membership in the R-TWT for the next time. If this field is set for the ML R-TWT response which accepts a ML R-TWT request, then this field indicates the start time of the first SP of the R-TWT after the R-TWT scheduled MLD receives this field and becomes the member of the R-TWT.

A Target Wake Time field can be set by using one of the following options. In Option**1** the Target Wake Time field is set to the TSF time of the STA which sends this field. In Option**2** the Target Wake Time field is set to the TSF time of the link which is indicated in the Link Info field of the same Broadcast ML TWT Parameter Set Field if the Link Info is only allowed to indicate one link. In Option**3** the Target Wake Time field is set to the TSF time of the link which is indicated in the Link Info field in the Control field of the ML TWT element if the Link Info is only allowed to indicate one link. In Option**4** the Target Wake Time field is set to the TSF time of the link which is the first bit (the MSB or the LSB in Link bitmap as shown in FIG. **32** or the first LinkID field as shown in FIG. **33** through FIG. **35**) of the Link Info field.

A nominal minimum TWT Wake Duration field is set to indicate the R-TWT SP duration. A TWT Wake Interval Mantissa field and the TWT Wake Interval Exponent field as shown in FIG. **29** are set to represent the interval between the R-TWT SPs, which is similar to those as defined in IEEE 802.11ax. A Broadcast TWT Info field can be as shown in FIG. **30**. A Restricted TWT Traffic Info field is present when the Restricted TWT Traffic Info Present field as shown in FIG. **30** is set to a first state (e.g., "1"), and this field can be identical to that defined in IEEE 802.11be. A Broadcast ML TWT ID field is set to indicate the MLD level R-TWT ID of the ML R-TWT. The receiver can use this field to identify the ML R-TWT.

A Link Info field is set to indicate which links the content of the broadcast ML TWT Parameter Set field is applied to. When the receiver receives this field, it now has information on which links the content of the broadcast ML TWT Parameter Set field is applied to and forwards those parameters to the STAs operating on those links. For example, if a MLD receives a Broadcast ML TWT Parameter Set Field on link**1** and the Link Info field of the Broadcast ML TWT Parameter Set Field is set to link**2**, then the Broadcast ML TWT Parameter Set Field is for the R-TWT SP scheduled on link**2**. The MLD may forward the Broadcast ML TWT Parameter Set Field to its affiliated STA on link**2**. The format of the Link Info field can be one of the figures between FIG. **31** through FIG. **35**.

FIG. **29** illustrates an example embodiment **410** of the Request Type field of the Broadcast ML TWT Parameter Set Field. The fields of TWT Request field, TWT Setup Commands, Trigger, Last Broadcast Parameter Set, Flow Type, Broadcast TWT Recommendation and TWT Wake Interval Exponent field can be identical to those defined in IEEE 802.11ax.

A Trigger-based Only field is set to indicate whether the ML R-TWT scheduled MLDs are allowed to contend for the channel during the R-TWT SPs. In at least one embodiment this field can be a one bit indication. For example, if this field is set to a first state (e.g., "1"), then the UL traffic transmission of the R-TWT member can only be triggered by the ML R-TWT scheduling AP MLD during the R-TWT SPs. If this field is set to a second state (e.g., "0"), then the R-TWT member can contend and access the channel for UL traffic transmission during the R-TWT SPs.

In at least one embodiment/mode/option when the Broadcast TWT Recommendation field is set to indicate the Broadcast ML TWT Parameter Set field is for R-TWT (e.g.,

value 4), the Trigger field works as the Trigger Based Only field and the Trigger based Only field is not needed.

FIG. **30** illustrates an example embodiment **430** of the Request Type field of the Broadcast ML TWT Parameter Set Field, having the following subfields.

A Restricted TWT Traffic Info Present field, in at least one embodiment, is a one bit indication to indicate whether the Restricted TWT Traffic Info field is present in the Broadcast ML TWT Parameter Set Field, which can be identical to that seen in FIG. **7**.

An ML TWT ID Present field is set to indicate whether the Broadcast ML TWT ID field in the Broadcast ML TWT Parameter Set Field as shown in FIG. **28** is present or not. In at least one embodiment this field can be one bit indication. For example, when this field is set to a first state (e.g., "1"), then the Broadcast ML TWT ID field is present in the Broadcast ML TWT Parameter Set Field. Otherwise, this field is set to a second state (e.g., "0") and the Broadcast ML TWT ID field is not present in the Broadcast ML TWT Parameter Set Field.

A Link Info Present field, can be in at least one embodiment, a one bit indication to indicate whether the Link Info field is present in the Broadcast ML TWT Parameter Set Field as shown in FIG. **28**. For example, when this field is set to a first state (e.g., "1"), then the Link Info field is present in the Broadcast ML TWT Parameter Set Field. Otherwise, it is set to a second state (e.g., "0") and the Link Info field is not present in the Broadcast ML TWT Parameter Set Field. Then, the Broadcast ML TWT Parameter Set Field is for the ML R-TWT parameter setting on the link it is transmitted.

A Broadcast TWT ID field is set to indicate the link level R-TWT ID of the SL R-TWT. The parameters in the Broadcast ML TWT Parameter Set Field are for those specific SL R-TWT(s) on the link indicated in the Link Info field.

A Broadcast TWT Persistence field can be identical to that defined in IEEE 802.11ax.

In at least one embodiment/mode/option the ML TWT ID Present field is set to indicate whether to set the Broadcast TWT ID to MLD level R-TWT ID or link level R-TWT ID. When the ML TWT ID Present field is set to a first state (e.g., "1"), then the Broadcast TWT ID field is set to indicate the MLD level R-TWT ID. When the ML TWT ID Present field is set to a second state (e.g., "0"), then the Broadcast TWT ID field is set to indicate the link level R-TWT ID; whereby the Broadcast ML TWT ID field in the Broadcast ML TWT Parameter Set Field is then not needed.

FIG. **31** through FIG. **35** illustrate five options **450**, **470**, **490**, **510** and **530** for the format of Link Info field, presented by way of example and not limitation.

In Option **1** of FIG. **31** the Link Info field can only carry one Link ID field. The link ID field is set to represent one link that the information is applied to.

In Option **2** of FIG. **32**, the Link Info field can carry one link bitmap field. This field can be the same as it is defined in IEEE 802.11be. The link bitmap field consists of multiple bits. Each bit represents a link. If a bit is set to a first state (e.g., "1"), then it represents that the information is applied to the corresponding link of that bit. Otherwise, a bit is set to a second state (e.g., "0") then this indicates that the information is not applied to the corresponding link of that bit.

In Option **3** of FIG. **33**, the Link Info field can carry multiple Link ID fields. Each Link ID field is set to represent one link that the information is applied to. A More Link ID field is set to indicate whether there is another Link ID field following it. For example, if the More Link ID field is set to a first state (e.g., "1"), then there is another Link ID field following it. Otherwise, this field is set to a second state (e.g., "0") and there is no Link ID field following it.

In Option **4** of FIG. **34**, the Link Info field can carry multiple Link ID fields. Each Link ID field is set to represent one link that the information is applied to. The Last Link ID field is set to indicate whether there is another Link ID field following it. If, for example, the Last Link ID field is set to a second state (e.g., "0"), then there is another Link ID field following it. Otherwise, this field is set to a first state (e.g., "1") and there is no Link ID field following it.

In Option **5** of FIG. **35**, the Link Info field can carry multiple Link ID fields. Each link ID field is set to represent one link that the information is applied to. Before the Link ID fields, there is a Number of Link ID field. This field is set to indicate the number of Link ID fields in the Link Info field.

It should be noted that the format of Link Info field in a ML TWT element for the ML R-TWT scheduling announcement can be different from the format of the Link Info field in a ML TWT element for the ML R-TWT setup (membership negotiation).

In at least one embodiment/mode/option the ML TWT Indication field is not needed since the Broadcast ML TWT Parameter Set Field contains a Link Info Present field and a ML TWT ID Present field. Those two fields are preferably located at reserved bits of the Broadcast TWT Parameter Set Field as shown in FIG. **5**. If for example they are set to a second state (e.g., "0"), then the Broadcast ML TWT Parameter Set Field is the same as the Broadcast TWT Parameter Set Field as shown in FIG. **5**.

4.7. Examples

This section provides multiple examples of ML R-TWT signaling. The network topology in these examples is shown as in FIG. **16**. In the examples of this section, SL R-TWTx represents a SL R-TWT with link level R-TWT ID=x; while ML R-TWTy represents a ML R-TWT with MLD level R-TWT ID=y.

In these examples of frame exchange, a pair of "{ }" in a frame represents a ML TWT element. The content between "{ }" represents the content in that ML TWT element. A pair of "< >" in a ML TWT element represents a Broadcast ML TWT Parameter Set Field. The content between "< >" represents the content in that Broadcast ML TWT Parameter Set Field. For example, {<SL R-TWT**1**, link**1**, **2**>, <SL R-TWT**2**, link**1**>} represents a ML TWT element carrying two Broadcast ML TWT Parameter Set fields. One Broadcast ML TWT Parameter Set field is for a SL R-TWT**1** whose SPs are scheduled on link**1** (SL R-TWT**1** on link**1**) and another SL R-TWT**1** whose SPs are scheduled on link**2** (SL R-TWT**1** on link**1**). Another Broadcast ML TWT Parameter Set field is for a SL R-TWT**2** whose SPs are scheduled on link**1** (SL R-TWT**2** on link**1**). {<SL R-TWT**1**, ML R-TWT**2**, link**1**, **2**>} represents an ML TWT element carrying one Broadcast ML TWT Parameter Set field which is for SL R-TWT**1** on link**1** and link**2** that belong to ML R-TWT**2**.

4.7.1. Link Info per Broadcast ML TWT Parameter Set Field

This section also considers the scenario that only the Link Info field is present per Broadcast ML TWT Parameter Set Field as shown in FIG. **28**. That is, the Link Info field is not present in the Control field of the ML TWT element as shown in FIG. **27**.

4.7.1.1. Implicit ML R-TWT

This section considers the scenario when an implicit ML R-TWT consists of one or more SL R-TWTs. Each SL

R-TWT is assigned to a unique link level R-TWT ID by the R-TWT scheduled AP on its link. The R-TWT scheduling AP MLD does not assign ML level R-TWT ID to a ML R-TWT. That is, the Broadcast ML TWT ID field is not present in the Broadcast ML TWT Parameter Set field as shown in FIG. **28**.

In the examples of this section, AP**1** schedules SL R-TWT**4** on link**1**. AP**2** schedules SL R-TWT**2** and SL R-TWT**4** on link**2**. The scheduling of SL R-TWT**4***s* on link**1** and link**2** is the same (i.e., their SP start time, SP duration, and interval between SPs are the same) but the scheduling of SL R-TWT**2** is different from the other two. According to Section 4.3, the SL R-TWT**4** on link**1** and link**2** can be considered as an implicit ML R-TWT and the SL R-TWT**2** can be considered as another implicit ML R-TWT.

FIG. **36** illustrates an example embodiment **610** of R-TWT scheduling with the AP announcing the ML R-TWT SP scheduling on its own link only. By way of example and not limitation, the figure depicts interactions between MLD**1** **70** with AP**1** **76** and AP**2** **78** and MLD**3** **74** with STA**3** **84** and STA**5** **88**.

When AP**1** sends a beacon **614** on link**1**, the beacon carries a ML TWT element. The ML TWT element carries a Broadcast ML TWT Parameter Set field to indicate the SL R-TWT**4** SP scheduling start **620** and duration **624** on link**1** only. It should be noted that the Broadcast ML TWT Parameter Set field of SL R-TWT**4** does not contain a Link Info field which indicates that it is for SL R-TWT**4** on link**1**.

When AP**2** sends a beacon **612** on link**2**, the beacon carries a ML TWT element. The ML TWT element carries two Broadcast ML TWT Parameter Set fields. One indicates the scheduling of SL R-TWT**2** **616** on link**2** and the other one indicates the scheduled start **618** and duration **624** of SL R-TWT**4** on link**2**.

During the SL R-TWT**4** SP on link**1** **620** and link**2** **618**, AP**1** and AP**2** can exchange frames with the members of SL R-TWT**4** on link**1** and link**2**. During the SL R-TWT**4** SP on link**1** and link**2**, AP**1** and AP**2** can exchange frames with the members of SL R-TWT**4** on link**1** and link**2**, respectively. As shown in the figure, SL R-TWT**4** on link**1** and link**2** is trigger-based only. Then AP**1** and AP**2** access the channel to trigger UL and DL transmissions. The members of SL R-TWT**4** on link**1** and link**2** should not access the channel during the SL R-TWT**4** SP on link**1** and link**2**.

During the SL R-TWT**2** SP on link**2**, AP**2** can exchange frames with the members of SL R-TWT**2** on link**2**. As shown in the figure, SL R-TWT**2** on link**2** is not trigger-based only. Then, if STA**5** is a member of SL R-TWT**2** on link**2**, it can contend for and access the channel to exchange frames with AP**2** during the SL R-TWT**2** SP on link**2**.

AP**1** is seen sending Trigger Frame (TF) **622***a*, and AP**2** sending TF **622***b*, to which STA**3** and STA**5**, respectively, respond with UL PPDU **626***a* and **626***b*. Upon receiving the transmission, the APs respond with BA **628***a* and **628***b*. AP**1** and AP**2** are seen sending DLMU PPDUs **630***a* and **630***b*, and receiving BAs **632***a*, **632***b* from STA**3** and STA**5** respectively. Each of these transmissions are depicted as being aligned for links of a Non-Simultaneous Transmit-Receive (NSTR) link pair. Then in an SL R-TWT**2** SP on link**2** **634**, STA**5** sends a non-triggered UL PPDU **636** and receives a BA **638** from AP**2**.

It should be noted that in the above case, there is no need of the Link info field. The format of ML TWT element can be the same as TWT element. That is, the ML TWT element can be decoded by STAs which supports broadcast TWT as defined in IEEE 802.11ax. Therefore, the ML TWT element can also be used to announce the broadcast TWT scheduling.

It should be noted that PPDU alignment during SL R-TWT**4** SP on link**1** and link**2** is not needed if link**1** and link**2** are not links of an NSTR link pair.

FIG. **37** illustrates an example embodiment **710** of a R-TWT scheduling AP announcing SL R-TWT scheduling on all the links. In this example, a link Info field in the Broadcast ML TWT Parameter Set Field can represent multiple links. That is, the format of the link Info field can be as shown in FIG. **32** through FIG. **35**. By way of example and not limitation, the figure depicts interactions between MLD**1** **70** with AP**1** **76** and AP**2** **78** and MLD**3** **74** with STA**3** **84** and STA**5** **88**.

AP**1** sends a beacon **714** carrying a ML TWT element on link**1**. The ML TWT element carries two Broadcast ML TWT Parameter Set fields. One field indicates the scheduling of SL R-TWT**2** **722** on link**2**; while the other one indicates the scheduling of SL R-TWT**4** **724** on link**1** and link**2**. The Target Wake Time fields of the Broadcast ML TWT Parameter Set fields are set to the TSF time of AP**1**.

AP**2** sends a beacon **712** carrying a ML TWT element on link**2**. The ML TWT element carries two Broadcast ML TWT Parameter Set fields. One indicates the scheduling of SL R-TWT**2** **716** on link**2**. The other one indicates the scheduling of SL R-TWT**4** start **718** and duration **724** on link**1** and link**2**. The Target Wake Time fields of the Broadcast ML TWT Parameter Set fields in the ML TWT element are set to the TSF time of AP**2**.

The remainder of the figure is the same as in FIG. **36**, with AP**1** sending Trigger Frame (TF) **726***a*, and AP**2** sending TF **726***b*, to which STA**3** and STA**5**, respectively, respond with UL PPDU **728***a* and **728***b*. Upon receiving the transmission, the APs respond with BA **730***a* and **730***b*. AP**1** and AP**2** are seen sending DLMU PPDUs **732***a* and **732***b*, and receiving BAs **734***a*, **734***b* from STA**3** and STA**5** respectively. Each of these transmissions are depicted as being aligned for links of an NSTR link pair. Then in an SL R-TWT**2** SP **736** on link**2** STA**5** sends a non-triggered UL PPDU **738** and receives a BA **740** from AP**2**.

FIG. **38** illustrates another example embodiment **810** of the R-TWT scheduling AP announcing SL R-TWT scheduling on all the links. In this example, a link Info field in the Broadcast ML TWT Parameter Set Field can only represent one link. That is, the format of the link Info field can be as shown in FIG. **31** or FIG. **32** (e.g., only one bit can be set to "1"). Again, the figure depicts, by way of example and not limitation, interactions between MLD**1** **70** with AP**1** **76** and AP**2** **78** and MLD**3** **74** with STA**3** **84** and STA**5** **88**.

AP**1** sends a beacon **814** carrying a ML TWT element on link**1**. The ML TWT element carries three Broadcast ML TWT Parameter Set fields. The first one indicates the scheduling of SL R-TWT**2** **821** on link**2**. The second and third ones indicate the scheduling of SL R-TWT**4** start **820** and duration **824** on link**1** and link**2**. The Target Wake Time field of a Broadcast ML TWT Parameter Set field is set to the TSF time of the AP on the link indicated in the Link Info field of that Broadcast ML TWT Parameter Set field. For example, the Target Wake Time field of a Broadcast ML TWT Parameter Set field of SL R-TWT**2** on link**2** is set to TSF time of AP**2** on link**2**.

AP**2** sends a beacon **812** carrying a ML TWT element on link**2**. The ML TWT element is identical to that in the beacon transmitted on link**1**.

The remainder of the figure is like FIG. **36**, with AP**1** sending Trigger Frame (TF) **822***a*, and AP**2** sending TF **822***b*, to which STA**3** and STA**5**, respectively, responds with UL PPDU **826***a*, **826***b*. Upon receiving the transmission, the APs respond with BA **828***a* and **828***b*. AP**1** and AP**2** are seen

sending DLMU PPDUs **830***a* and **830***b*, and receiving BAs **832***a*, **832***b* from STA**3** and STA**5** respectively. Each of these transmissions are depicted as being aligned for links of an NSTR link pair. Then in an SL R-TWT**2** SP **834** on link**2** STA**5** sends a non-triggered UL PPDU **836** and receives a BA **838** from AP**2**.

FIG. **39** illustrates an example embodiment **910** of R-TWT scheduling with AP announcements of ML R-TWT scheduling of SPs on its link. In this example, a link Info field in the Broadcast ML TWT Parameter Set Field can represent multiple links. That is, the format of the link Info field can be as shown in FIG. **32** through FIG. **35**. Again, the figure depicts, by way of example and not limitation, interactions between MLD**1** **70** with AP**1** **76** and AP**2** **78** and MLD**3** **74** with STA**3** **84** and STA**5** **88**.

AP**1** sends a beacon **914** carrying a ML TWT element on link**1**. Since SL R-TWT**4** on link**1** and SL R-TWT**4** on link**2** are considered as a ML R-TWT, the ML TWT element carries one Broadcast ML TWT Parameter Set field which indicates the scheduling of SL R-TWT**4** start **920** and duration **924** on link**1** and link**2**. The Target Wake Time fields of the Broadcast ML TWT Parameter Set fields are set to the TSF time of AP**1**.

AP**2** sends a beacon **912** carrying a ML TWT element on link**2**. The ML TWT element carries two Broadcast ML TWT Parameter Set fields. One indicates the scheduling of SL R-TWT**2** **916** on link**2**. The other one indicates the scheduling of SL R-TWT**4** start **918** and duration **924** on link**1** and link**2** since SL R-TWT**4** on link**1** and SL R-TWT**4** on link**2** are considered as a ML R-TWT. The Target Wake Time fields of the Broadcast ML TWT Parameter Set fields in the ML TWT element are set to the TSF time of AP**2**.

The remainder of the figure is the same as FIG. **38**, with AP**1** sending Trigger Frame (TF) **922***a*, and AP**2** sending TF **922***b*, to which STA**3** and STA**5**, respectively, respond with UL PPDU **926***a*, **926***b*. Upon receiving the transmission, the APs respond with BA **928***a* and **928***b*. AP**1** and AP**2** are seen sending DLMU PPDUs **930***a* and **930***b*, and receiving BAs **932***a*, **932***b* from STA**3** and STA**5** respectively. Each of these transmissions are depicted as being aligned for links of an NSTR link pair. Then in an SL R-TWT**2** SP **934** on link**2** STA**5** sends a non-triggered UL PPDU **936** and receives a BA **938** from AP**2**.

FIG. **40** illustrates an example embodiment **1010** of a ML R-TWT setup procedure. Again, the figure depicts, by way of example and not limitation, interactions between MLD**1** **70** with AP**1** **76** and AP**2** **78** and MLD**3** **74** with STA**3** **84** and STA**5** **88**.

An ML R-TWT membership negotiation commences **1012** with STA**3** transmitting a ML R-TWT request frame **1014** to AP**1** over link**1** to request the membership of SL R-TWT**2** whose SPs are scheduled on link**2**. After AP**1** receives this request, it sends a ML R-TWT response **1016** back to indicate that the membership request is accepted. It can also indicate the start time **1018** of the first SL R-TWT**2** SP for STA**5** on link**2**. Then, STA**5** becomes the member STA of SL R-TWT**2**. During the SL R-TWT**2** SP **1020**, STA**5** can contend for the channel and transmit UL PPDUs **1024** and **1028** to AP**2** if the SL R-TWT**2** is not triggered-based only. The figure also shows AP**2** responding to receipt of the UL PPDUs with BAs **1026** and **1030**.

The interval **1022** between SL R-TWT**2** SPs on link**2** is determined from the parameters set during ML R-TWT setup. The purpose is to indicates that a R-TWT schedule will have multiple SPs periodically. Outside of the R-TWT SP, all the STAs use the EDCA to contend for the channel as defined in IEEE 802.11ax except that the R-TWT scheduled STAs shall end their TXOPs before the start time of the upcoming R-TWT SP.

FIG. **41** illustrates an example embodiment **1110** of ML R-TWT setup procedure when the Link Info field is not present in the Broadcast ML TWT Parameter Set field. Again, the figure depicts, by way of example and not limitation, interactions between MLD**1** **70** with AP**1** **76** and AP**2** **78** and MLD**3** **74** with STA**3** **84** and STA**5** **88**.

An ML R-TWT membership negotiation **1112** commences with STA**5** sending a ML R-TWT request frame **1114** to AP**2** over link**2** to request the membership of SL R-TWT**2** whose SPs are scheduled on link**2**. After AP**2** receives this request, it sends a ML R-TWT response **1116** back to indicate that the membership request is accepted. It can also indicate the start time **1118** of the first SL R-TWT**2** SP for STA**5** on link**2**. Then, STA**5** becomes the member STA of SL R-TWT**2** **1122**. During the SL R-TWT**2** SP **1122**, STA**5** can contend for the channel and transmit UL PPDUs **1124** and **1128** to AP**2** if the SL R-TWT**2** is not triggered-based only. The figure also shows AP**2** responding to receipt of the UL PPDUs with BAs **1126** and **1130**.

The interval **1120** between SL R-TWT**2** SPs on link**2** is determined from the parameters set during ML R-TWT setup. The purpose is to indicates that a R-TWT schedule will have multiple SPs periodically. Outside of the R-TWT SP, all the STAs use the EDCA to contend for the channel as defined in IEEE 802.11ax except that the R-TWT scheduled STAs shall end their TXOPs before the start time of the upcoming R-TWT SP.

It should be noted that in this case, there is no need of the Link info field. The format of ML TWT element can be the same as the TWT element. That is, the ML TWT element can be decoded by STAs which support broadcast TWT as defined in IEEE 802.11ax. Therefore, the ML TWT element can also be used for the broadcast TWT setup.

FIG. **42** illustrates an example embodiment **1210** of a ML R-TWT setup procedure over multiple links. Again, the figure depicts, by way of example and not limitation, interactions between MLD**1** **70** with AP**1** **76** and AP**2** **78** and MLD**3** **74** with STA**3** **84** and STA**5** **88**.

An ML R-TWT membership negotiation **1212** commences with STA**3** sending a ML R-TWT request frame **1214** to AP**1** over link**1** to request the membership of SL R-TWT**2** whose SPs are scheduled on link**2**. After AP**1** receives this request, it sends an ACK frame **1216** to indicate the request has been received.

Then AP**1** forwards this request (not shown as it is an intra-MLD transfer) to AP**2**. AP**2** then sends a ML R-TWT response **1218** over link**2** to indicate that the membership request has been accepted. It can also indicate the start time **1222** of the first SL R-TWT**2** SP for STA**5** on link**2**. Then, STA**5** sends an ACK frame **1220** to indicate it has received the response and STA**5** has become a member STA of SL R-TWT**2**. During SL R-TWT**2** SP **1226**, STA**5** can contend for the channel and transmit UL PPDUs **1228** and **1232** to AP**2** if the SL R-TWT**2** is not triggered-based only. The figure also shows AP**2** responding to receipt of the UL PPDUs with BAs **1230** and **1234**.

The interval **1224** between SL R-TWT**2** SPs on link**2** is determined from the parameters set during ML R-TWT setup. The purpose is to indicates that a R-TWT schedule will have multiple SPs periodically. Outside of the R-TWT SP, all the STAs use the EDCA to contend for the channel as defined in IEEE 802.11ax except that the R-TWT scheduled STAs shall end their TXOPs before the start time of the upcoming R-TWT SP.

FIG. **43** illustrates an example embodiment **1310** of a ML R-TWT setup procedure for a ML R-TWT over a link. In this example, the ML R-TWT consists of SL R-TWT**4** on link**1** and SL R-TWT**4** on link**2**. A link Info field in the Broadcast ML TWT Parameter Set Field can represent multiple links. That is, the format of the link Info field can be as shown in FIG. **32** through FIG. **35**. Again, the figure depicts, by way of example and not limitation, interactions between MLD**1** **70** with AP**1** **76** and AP**2** **78** and MLD**3** **74** with STA**3** **84** and STA**5** **88**.

An ML R-TWT membership negotiation **1312** commences with STA**3** sending a ML R-TWT request frame **1314** to AP**1** over link**1** to request the membership of SL R-TWT**4** scheduled on link**1** and link**2**. After AP**1** receives this request, it sends a ML R-TWT response frame **1316** back to indicate that the membership request is accepted. The Target Wake Time field of the Broadcast ML TWT Parameter Set field of SL R-TWT**4** is set to indicate the start time **1318** of the first SL R-TWT**4** SP for STA**3** on link**1** and for STA**5** on link**2** in the TSF time of AP**1** (on link**1**).

Then, STA**3** becomes a member STA of R-TWT**4** on link**1** and STA**5** becomes the member STA of R-TWT**4** **1322** on link**2**. During SL R-TWT**4** SPs on link**1** and link**2**, STA**3** and STA**5** exchange frames with AP**1** and AP**2**, respectively. Thus, AP**1** is shown transmitting DL PPDUs **1324***a* and **1328***a*, and receiving BAs **1326***a* and **1330***a* from STA**3**; while AP**2** is shown transmitting DL PPDUs **1324***b* and **1328***b*, and receiving BAs **1326***b* and **1330***b* from STA**5**.

The interval **1320** between SL R-TWT**4** SPs on link**1** is determined from the parameters set during ML R-TWT setup. The purpose is to indicates that a R-TWT schedule will have multiple SPs periodically. Outside of the R-TWT SP, all the STAs use the EDCA to contend for the channel as defined in IEEE 802.11ax except that the R-TWT scheduled STAs shall end their TXOPs before the start time of the upcoming R-TWT SP.

FIG. **44** illustrates an example embodiment **1410** of a ML R-TWT setup procedure for a ML R-TWT. In this example, the ML R-TWT consists of SL R-TWT**4** on link**1** and SL R-TWT**4** on link**2**. Compared with the previous example, a link Info field in the Broadcast ML TWT Parameter Set Field can only represent one link. That is, the format of the link Info field can be as shown in FIG. **31** or FIG. **32** (e.g., only one bit can be set to "1"). Again, the figure depicts, by way of example and not limitation, interactions between MLD**1** **70** with AP**1** **76** and AP**2** **78** and MLD**3** **74** with STA**3** **84** and STA**5** **88**.

An ML R-TWT membership negotiation **1412** commences with STA**3** sending a ML R-TWT request frame to AP**1** over link**1** to request the membership of SL R-TWT**4** scheduled on link**1** and link**2**. After AP**1** receives this request, it sends a ML R-TWT response frame **1416** back to indicate that the membership request is accepted.

The ML R-TWT request/response frames contain a ML TWT element with two Broadcast ML TWT Parameter Set fields for SL R-TWT**4** on link**1** and link**2**. The Target Wake Time field of the Broadcast ML TWT Parameter Set field for SL R-TWT**4** on link**1** is set to indicate the start time **1418** of the first SL R-TWT**4** SP for STA**3** on link**1** in the TSF time of AP**1** (on link**1**). The Target Wake Time field of the Broadcast ML TWT Parameter Set field for SL R-TWT**4** on link**2** is set to indicate the start time **1420** of the first SL R-TWT**4** SP for STA**5** on link**2** in the TSF time of AP**2** (on link**2**).

Then, STA**3** becomes the member STA of R-TWT**4** on link**1** and STA**5** becomes the member STA of R-TWT**4** on link**2**. During SL R-TWT**4** SPs on link**1** and link**2**, STA**3** and STA**5** exchange frames with AP**1** and AP**2**, respectively. In particular, AP**1** is shown transmitting DL PPDUs **1426***a* and **1430***a*, and receiving BAs **1428***a* and **1432***a* from STA**3**; while AP**2** is shown transmitting DL PPDUs **1426***b* and **1430***b*, and receiving BAs **1428***b* and **1432***b* from STA**5**.

The interval **1422** between SL R-TWT**4** SPs on link **1** and link**2** is determined from the parameters set during ML R-TWT setup. The purpose is to indicates that a R-TWT schedule will have multiple SPs periodically. Outside of the R-TWT SP, all the STAs use the EDCA to contend for the channel as defined in IEEE 802.11ax except that the R-TWT scheduled STAs shall end their TXOPs before the start time of the upcoming R-TWT SP.

FIG. **45** illustrates an example embodiment **1510** of a ML R-TWT setup procedure for a ML R-TWT in which only a partial request is accepted. In this example, the ML R-TWT consists of SL R-TWT**4** on link**1** and SL R-TWT**4** on link**2**. In this example a link Info field in the Broadcast ML TWT Parameter Set Field can only represent one link. That is, the format of the link Info field can be as shown in FIG. **31** or FIG. **32** (e.g., only one bit can be set to "1"). Again, the figure depicts, by way of example and not limitation, interactions between MLD**1** **70** with AP**1** **76** and AP**2** **78** and MLD**3** **74** with STA**3** **84** and STA**5** **88**.

An ML R-TWT membership negotiation **1512** commences with STA**3** sending a ML R-TWT request frame **1514** to AP**1** over link**1** to request the membership of SL R-TWT**4** scheduled on link**1** and link**2**. After AP**1** receives this request, it sends a ML R-TWT response frame **1516** back to indicate that only the membership request for SL R-TWT**4** on link**2** is accepted, and indicates its start time **1518**.

Thus, STA**5** becomes a member STA of R-TWT**4** on link**2**, while STA**3** is not a member STA of R-TWT**4** on link**1**. During SL R-TWT**4** SPs on link**2**, STA**5** exchanges frames with AP**2**. In particular, AP**2** is shown transmitting DL PPDUs **1524** and **1528**, and receiving BAs **1526** and **1530** from STA**5**.

The interval **1520** between SL R-TWT**4** SPs on link**1** and link**2** is determined from the parameters set during ML R-TWT setup. The purpose is to indicates that a R-TWT schedule will have multiple SPs periodically. Outside of the R-TWT SP, all the STAs use the EDCA to contend for the channel as defined in IEEE 802.11ax except that the R-TWT scheduled STAs shall end their TXOPs before the start time of the upcoming R-TWT SP.

4.7.1.2 Explicit ML R-TWT

This section considers the scenario when an explicit ML R-TWT consists of one or more SL R-TWTs. Each SL R-TWT is assigned to a unique link level R-TWT ID by the R-TWT scheduled AP on its link. The R-TWT scheduling AP MLD also assigns ML level R-TWT IDs to its ML R-TWTs. In particular, the Broadcast ML TWT ID field presents in the Broadcast ML TWT Parameter Set field as shown in FIG. **28** if it is for SL R-TWT(s) belonging to a ML R-TWT.

In the examples of this section, AP**1** schedules SL R-TWT**1** on link**1**. MLD**1** schedules a ML R-TWT**1** consisting of SL R-TWT**2** on link**1** and link**2**.

FIG. **46** illustrates an example embodiment **1610** of R-TWT scheduling with an AP announcing the SL R-TWT scheduling and ML R-TWT scheduling in a ML TWT element. Again, the figure depicts, by way of example and not limitation, interactions between MLD**1** **70** with AP**1** **76** and AP**2** **78** and MLD**3** **74** with STA**3** **84** and STA**5** **88**.

AP**1** sends a beacon **1614** on link**1** carrying a ML TWT element. The ML TWT element contains two Broadcast ML

TWT Parameter Set fields. One element is for scheduling SL R-TWT1 1622 and scheduling a subsequent SL R-TWT1 1620 on link2. The other one is for SL R-TWT2 on link1 and link2.

AP2 also sends a beacon 1612 on link1 carrying a SL TWT element. The SL TWT element contains two Broadcast ML TWT Parameter Set fields. One is for scheduling SL R-TWT1 1618 (same for link1 and link2) and the other for subsequent 1616 on link2 only. The other one is for SL R-TWT2 consisting of SL R-TWT2 1626 on link1 and link2.

Then, during the ML R-TWT1 SPs 1626, MLD1 can exchange frames with the members of the ML R-TWT1 on link1 and link2. During the SL R-TWT1 SPs, AP2 can exchange frames with the members of the SL R-TWT1 on link2. In particular, AP1 is seen sending TF 1624*a*, receiving UL PPDU 1628*a*, sending BA 1630*a* and DLMU PPDU 1632*a*, and receiving BA 1634*a*; while AP2 is seen sending TF 1624*b*, receiving UL PPDU 1628*b*, sending BA 1630*b* and DLMU PPDU 1632*b*, and receiving BA 1634*b*.

After the end of SL R-TWT1 SP 1616 on link 2, then another SL R-TWT1 SP 1636 on link 2 commences with STA5 transmitting UL PPDU 1638 and receiving BA 1640.

FIG. 47 illustrates an example embodiment 1710 of a ML R-TWT setup using MLD level R-TWT ID. In this example, MLD3 knows (has determined) that MLD1 has scheduled a ML R-TWT1 consisting of SL R-TWT2 on link1 and link2 as was shown in FIG. 46. Then it can request the membership of ML R-TWT1 using the MLD level R-TWT ID. Again, the figure depicts, by way of example and not limitation, interactions between MLD1 70 with AP1 76 and AP2 78 and MLD3 74 with STA3 84 and STA5 88.

An ML R-TWT membership negotiation 1712 commences with STA3 sending a ML R-TWT request frame 1714 to AP1 over link1 to request the membership of ML R-TWT1. After AP1 receives this request, it sends a ML R-TWT response frame 1716 back to indicate that the membership request is accepted, as well as a start time 1718 and end 1722.

Thus, MLD3 becomes a member of ML R-TWT1. During ML R-TWT1 SPs 1723 on link1 and link2, STA3 and STA5 exchange frames with AP1 and AP2, respectively. In particular, AP1 is shown transmitting DL PPDUs 1720*a* and 1726*a*, and receiving BAs 1724*a* and 1728*a* from STA3; while AP2 is shown transmitting DL PPDUs 1720*b* and 1726*b*, and receiving BAs 1724*b* and 1728*b* from STA5.

The interval 1722 between ML R-TWT1 SPs on link 1 and link2 is determined from the parameters set during ML R-TWT setup. The purpose is to indicates that a R-TWT schedule will have multiple SPs periodically. Outside of the R-TWT SP, all the STAs use the EDCA to contend for the channel as defined in IEEE 802.11ax except that the R-TWT scheduled STAs shall end their TXOPs before the start time of the upcoming R-TWT SP.

4.7.2. Link Info Field per ML TWT Element

This section considers the same scenario as discussed in Section 4.7.1.1 except that the Link Info field is present in the Control Field.

FIG. 48 illustrates an example embodiment 1810 of R-TWT scheduling with the AP announcing all the ML R-TWT scheduling of its affiliated AP MLD. In this example, a link Info field in the Broadcast ML TWT Parameter Set Field can represent multiple links. That is, the format of the link Info field can be as shown in FIG. 32 through FIG. 35. Again, the figure depicts, by way of example and not limitation, interactions between MLD1 70 with AP1 76 and AP2 78 and MLD3 74 with STA3 84 and STA5 88.

AP1 sends a beacon 1814 carrying two ML TWT elements on link1. The first ML TWT element carries one Broadcast ML TWT Parameter Set field to schedule 1821 SL R-TWT2 1834. In the first ML TWT element, the Link Info Field in the Control field is set to "Link2" which indicates the SL R-TWT2 is scheduled on link2. The second ML TWT element carries one Broadcast ML TWT Parameter Set field for SL R-TWT4. In the second ML TWT element, the Link Info Field in the Control field is set to "Link1 and Link2" which indicates SL R-TWT4 scheduling 1820 for SL R-TWT4 1824 on link1 and link2.

AP2 sends a beacon 1812 carrying two ML TWT elements on link2. The two elements carry the SL R-TWT2 scheduling 1816 on link2 and SL R-TWT4 scheduling 1818 on link1 and link2 the same as the beacon sent by AP1.

The remainder of the figure is the same as FIG. 38, with AP1 sending TF 1822*a*, and AP2 sending TF 1822*b*, to which STA3 and STA5, respectively, respond with UL PPDU 1826*a*, 1826*b*. Upon receiving the transmissions, the APs respond with BAs 1828*a* and 1828*b*. AP1 and AP2 are seen sending DL MU PPDUs 1830*a* and 1830*b*, and receiving BAs 1832*a*, 1832*b* from STA3 and STA5 respectively. Each of these transmissions are depicted as being aligned for links of an NSTR link pair.

Then in an SL R-TWT2 SP 1834 on link2 STA5 sends a non-triggered UL PPDU 1836 and receives a BA 1838 from AP2.

In this example, the Target Wake Time field of a Broadcast ML TWT Parameter Set field is set to the TSF time of the AP which transmits the Broadcast ML TWT Parameter Set field. For example, the Target Wake Time field of a Broadcast ML TWT Parameter Set field sent on link1 is set to TSF time of AP1 on link1. The Target Wake Time field of a Broadcast ML TWT Parameter Set field sent on link2 is set to TSF time of AP2 on link2.

4.8. ML R-TWT Operation on Special MLD Links

This section describes some ML R-TWT operations on special MLD links, such as enhanced Multi-Link Single-Radio (eMLSR) link, enhanced Multi-Link Multi-Radio (eMLMR) links, and Non-Simultaneous Transmit-Receive (NSTR) links.

FIG. 49 illustrates an example embodiment 1910 of ML R-TWT Operations on Special MLD links. The network topology for the example is shown in FIG. 16. This example considers a scenario that: (a) MLD1 and MLD3 operates in eMLSR on link1 and link2, or (b) MLD1 and MLD3 operates in eMLMR mode whereby link1 and link2 are eMLMR links, or that (c) MLD3 is an NSTR MLD and link1 and link2 are a NSTR link pair of MLD3. Again, the figure depicts, by way of example and not limitation, interactions between MLD1 70 with AP1 76 and AP2 78 and MLD3 74 with non-AP STA3 84 and non-AP STA5 88.

In a ML R-TWT setup 1912, STA3 is seen requesting 1914 membership, in response to which AP1 responds with ML R-TWT response 1916 scheduling a SL R-TWT4 on link2 only, with schedule 1918 and duration 1922. Non-AP MLD3 negotiates membership of SL R-TWT4 with AP MLD1 and STA5 becomes a member of SL R-TWT4. During the SL R-TWT4 SP, STA5 can exchange the frames with AP2. Then, it is possible that STA3 has to end its TXOP on link1 1919 before the start time of R-TWT4 SP, and STA3 is not allowed to access 1920 the channel on link1 until the R-TWT4 SP ends or STA5 finishes its frame exchange with AP2 during the R-TWT4 SP.

When considering eMLSR/eMLMR delay, STA3 has to end its TXOP on link1 eMLSR/eMLMR at a given Delay time before the start time of R-TWT4 SP. AP1 is not allowed

to transmit to STA3 on link1 until R-TWT4 SP ends. It will be recognized that this delay time is specified in the associated EML capability fields, which can be indicated in an association procedure.

Communications are seen with AP2 completing Backoff (BO) **1926** and sending MU Ready-To-Send (RTS) **1928**, and receiving Clear-To-Send (CTS) **1930** from STA5. AP2 then sends DL PPDU **1932**, which upon receipt STA5 sends BA **1934**. After the interval between SL R-TWT4 SPs **1924**, then another SL R-TWT4 on link2 **1936** can commence.

It should be appreciated that similar conditions apply in regard to an AP operating as the TXOP and having to insure that its TXOP ends within a given amount of time before the start of R-TWT SP on a first special link.

5. General Scope of Embodiments

Embodiments of the present technology may be described herein with reference to flowchart illustrations of methods and systems according to embodiments of the technology, and/or procedures, algorithms, steps, operations, formulae, or other computational depictions, which may also be implemented as computer program products. In this regard, each block or step of a flowchart, and combinations of blocks (and/or steps) in a flowchart, as well as any procedure, algorithm, step, operation, formula, or computational depiction can be implemented by various means, such as hardware, firmware, and/or software including one or more computer program instructions embodied in computer-readable program code. As will be appreciated, any such computer program instructions may be executed by one or more computer processors, including without limitation a general purpose computer or special purpose computer, or other programmable processing apparatus to produce a machine, such that the computer program instructions which execute on the computer processor(s) or other programmable processing apparatus create means for implementing the function(s) specified.

Accordingly, blocks of the flowcharts, and procedures, algorithms, steps, operations, formulae, or computational depictions described herein support combinations of means for performing the specified function(s), combinations of steps for performing the specified function(s), and computer program instructions, such as embodied in computer-readable program code logic means, for performing the specified function(s). It will also be understood that each block of the flowchart illustrations, as well as any procedures, algorithms, steps, operations, formulae, or computational depictions and combinations thereof described herein, can be implemented by special purpose hardware-based computer systems which perform the specified function(s) or step(s), or combinations of special purpose hardware and computer-readable program code.

Furthermore, these computer program instructions, such as embodied in computer-readable program code, may also be stored in one or more computer-readable memory or memory devices that can direct a computer processor or other programmable processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory or memory devices produce an article of manufacture including instruction means which implement the function specified in the block(s) of the flowchart(s). The computer program instructions may also be executed by a computer processor or other programmable processing apparatus to cause a series of operational steps to be performed on the computer processor or other programmable processing apparatus to produce a computer-implemented process such that the instructions which execute on the computer processor or other programmable processing apparatus provide steps for implementing the functions specified in the block(s) of the flowchart(s), procedure (s) algorithm(s), step(s), operation(s), formula(e), or computational depiction(s).

It will further be appreciated that the terms "programming" or "program executable" as used herein refer to one or more instructions that can be executed by one or more computer processors to perform one or more functions as described herein. The instructions can be embodied in software, in firmware, or in a combination of software and firmware. The instructions can be stored local to the device in non-transitory media, or can be stored remotely such as on a server, or all or a portion of the instructions can be stored locally and remotely. Instructions stored remotely can be downloaded (pushed) to the device by user initiation, or automatically based on one or more factors.

It will further be appreciated that as used herein, that the terms processor, hardware processor, computer processor, central processing unit (CPU), and computer are used synonymously to denote a device capable of executing the instructions and communicating with input/output interfaces and/or peripheral devices, and that the terms processor, hardware processor, computer processor, CPU, and computer are intended to encompass single or multiple devices, single core and multicore devices, and variations thereof.

From the description herein, it will be appreciated that the present disclosure encompasses multiple implementations of the technology which include, but are not limited to, the following:

An apparatus for wireless communication in a network, the apparatus comprising: (a) a wireless communication circuit, as a wireless station (STA) which is a separate STA or as a STA in a multiple-link device (MLD), and operating as either a regular STA or an Access Point (AP) STA, for wirelessly communicating with other wireless stations (STAs) using a carrier sense multiple access/collision avoidance (CSMA/CA) mechanism on a wireless local area network (WLAN) in which enhanced distributed channel access (EDCA) is utilized for random channel access on all the links; (b) a processor coupled to said wireless communication circuit for operating on the WLAN; (c) a non-transitory memory storing instructions executable by the processor for communicating with other STAs; and (d) wherein said instructions, when executed by the processor, perform steps of a wireless communications protocol for said wireless communication circuit, comprising: (d)(i) scheduling a multi-link (ML) restricted target wait time (R-TWT), by an AP station whose service periods (SPs) are scheduled on multiple links; (d)(ii) receiving a ML R-TWT request frame from a non-AP multiple-link device (MLD) to negotiate its membership of the ML R-TWT; (d)(iii) responding to said ML R-TWT request frame by an MLD of said AP with a ML R-TWT response frame to indicate acceptance or rejection of the ML R-TWT request frame request from the non-AP MLD; and (d)(iv) wherein the non-AP MLD becomes a member of the ML R-TWT if the AP MLD accepts its request.

An apparatus for wireless communication in a network, the apparatus comprising: (a) a wireless communication circuit, as a wireless station (STA) which is a separate STA or as a STA in a multiple-link device (MLD), and operating as either a regular STA or an Access Point (AP) STA, for wirelessly communicating with other wireless stations (STAs) using a carrier sense multiple access/collision avoidance (CSMA/CA) mechanism on a wireless local area

network (WLAN) in which enhanced distributed channel access (EDCA) is utilized for random channel access on all the links; (b) a processor coupled to said wireless communication circuit for operating on the WLAN; (c) a non-transitory memory storing instructions executable by the processor for communicating with other STAs; and (d) wherein said instructions, when executed by the processor, perform steps of a wireless communications protocol for said wireless communication circuit, comprising: (d)(i) sending a frame containing multi-link (ML) target wait time (TWT) element for ML restricted-TWT (R-TWT) signaling by a non-AP STA; (d)(ii) wherein the ML TWT element carries one or more Broadcast ML TWT Parameter Set Fields; and (d)(iii) wherein the ML TWT element contains link information to indicate which links the information in the Broadcast ML TWT Parameter Set Fields is applied to as the R-TWT schedule is only scheduled on those links.

An apparatus for wireless communication in a network, the apparatus comprising: (a) a wireless communication circuit, as a wireless station (STA) which is a separate STA or as a STA in a multiple-link device (MLD), and operating as either a regular STA or an Access Point (AP) STA, for wirelessly communicating with other wireless stations (STAs) using a carrier sense multiple access/collision avoidance (CSMA/CA) mechanism on a wireless local area network (WLAN) in which enhanced distributed channel access (EDCA) is utilized for random channel access on all the links; (b) a processor coupled to said wireless communication circuit for operating on the WLAN; (c) a non-transitory memory storing instructions executable by the processor for communicating with other STAs; and (d) wherein said instructions, when executed by the processor, perform steps of a wireless communications protocol for said wireless communication circuit, comprising: (d)(i) setting up a multi-link (ML) restricted target wait time (R-TWT), by an AP station whose service periods (SPs) are scheduled on multiple links, and for which a non-AP multiple-link device (MLD) may negotiate membership in the ML R-TWT; (d)(ii) scheduling a communication over a special MLD link of a first station on a first MLD; and (d)(iii) requiring that the second station of that first MLD must end its transmit opportunity (TXOP), leaving a given delay period, before the start of the first station on that MLD exchanging frames over the special MLD link.

A wireless communication system/apparatus performing transmission of packets, where CSMA/CA is applied in the system/apparatus, comprising: (a) an AP MLD schedules a ML R-TWT whose SPs are scheduled on multiple links; (b) a non-AP MLD sends a ML R-TWT request frame to negotiate its membership of the ML R-TWT; (c) wherein the AP MLD responds with a ML R-TWT response frame to accept or reject the request from the non-AP MLD; and (d) wherein the non-AP MLD becomes a member of the ML R-TWT if the AP MLD accepts its request.

A wireless communication system/apparatus performing transmission of packets, where CSMA/CA is applied in the system/apparatus, comprising: (a) a STA sends a frame containing ML TWT element for ML R-TWT signaling; (b) wherein the ML TWT element carries one or more Broadcast ML TWT Parameter Set Fields; and (c) wherein the ML TWT element contains link information to indicate which links the information in the Broadcast ML TWT Parameter Set Fields is applied to.

The apparatus, method or system of any preceding implementation, wherein the AP MLD can announce the scheduling of the ML R-TWT in a beacon frame, a (ML) probe response frame, (re)association frame, or ML R-TWT scheduling announcement frame.

The apparatus, method or system of any preceding implementation, wherein an AP affiliated with the AP MLD can announce the scheduling of the ML R-TWT SPs on its own link only.

The apparatus, method or system of any preceding implementation, wherein an AP affiliated with the AP MLD can announce the scheduling of all the ML R-TWT scheduled by the AP MLD.

The apparatus, method or system of any preceding implementation, wherein an AP affiliated with the AP MLD can only announce the scheduling of the ML R-TWTs of which some of the SPs are scheduled on the same link of the AP.

The apparatus, method or system of any preceding implementation, wherein an AP affiliated with the AP MLD can announce the scheduling of the ML R-TWTs and SL R-TWTs in a same frame.

The apparatus, method or system of any preceding implementation, wherein a ML R-TWT can consist of one or more SL R-TWTs which are scheduled by the APs affiliated with the AP MLD on different links.

The apparatus, method or system of any preceding implementation, wherein the AP MLD can assign a unique ML level R-TWT ID to the ML R-TWT to identify the ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein the AP MLD can assign a same SL level R-TWT ID to the SL R-TWTs of the ML R-TWT to indicate that those SL R-TWTs belong to a same ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein the SL R-TWTs with a same SL level R-TWT ID in a same ML TWT element can be regarded as a ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein the SL R-TWTs with the same SP scheduling, e.g., same SP start time, SP duration, and SP interval, on different links can be regarded as a ML R-TWT.

The apparatus as recited in claim **1**, wherein the SL R-TWTs with a same ML level R-TWT ID can be regarded as a ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein ML R-TWT request or response frame can contain the link information to indicate the links where the corresponding ML R-TWT parameters are applied to.

The apparatus, method or system of any preceding implementation, wherein ML R-TWT request or response frame can contain one or more ML TWT element(s) which carries the ML R-TWT information for one or more links.

The apparatus, method or system of any preceding implementation, wherein AP MLD can accept the ML R-TWT membership request on partial links of the ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein the membership negotiation of a ML R-TWT can occur before AP MLD announces the scheduling of that ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein the ML TWT element can share the same element ID as TWT element.

The apparatus, method or system of any preceding implementation, wherein the ML TWT element can carry one link information field to indicate which links the information in all the Broadcast ML TWT Parameter Set Fields is applied to.

The apparatus, method or system of any preceding implementation, wherein each link information field can carry one link information field to indicate which links its information is applied to.

The apparatus, method or system of any preceding implementation, wherein the AP MLD can announce the scheduling of the ML R-TWT in a beacon frame, a (ML) probe response frame, (re)association frame, or ML R-TWT scheduling announcement frame.

The apparatus, method or system of any preceding implementation, wherein an AP affiliated with the AP MLD can announce the scheduling of the ML R-TWT SPs on its own link only.

The apparatus, method or system of any preceding implementation, wherein an AP affiliated with the AP MLD can announce the scheduling of all the ML R-TWT scheduled by the AP MLD.

The apparatus, method or system of any preceding implementation, wherein an AP affiliated with the AP MLD can only announce the scheduling of the ML R-TWTs of which some of the SPs are scheduled on the same link of the AP.

The apparatus, method or system of any preceding implementation, wherein an AP affiliated with the AP MLD can announce the scheduling of the ML R-TWTs and SL R-TWTs in a same frame.

The apparatus, method or system of any preceding implementation, wherein a ML R-TWT can consist of one or more SL R-TWTs which are scheduled by the APs affiliated with the AP MLD on different links.

The apparatus, method or system of any preceding implementation, wherein the AP MLD can assign a unique ML level R-TWT ID to the ML R-TWT to identify the ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein the AP MLD can assign a same SL level R-TWT ID to the SL R-TWTs of the ML R-TWT to indicate that those SL R-TWTs belong to a same ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein the SL R-TWTs with a same SL level R-TWT ID in a same ML TWT element can be regarded as a ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein the SL R-TWTs with the same SP scheduling, e.g., same SP start time, SP duration, and SP interval, on different links can be regarded as a ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein the SL R-TWTs with a same ML level R-TWT ID can be regarded as a ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein ML R-TWT request or response frame can contain the link information to indicate the links where the corresponding ML R-TWT parameters are applied to.

The apparatus, method or system of any preceding implementation, wherein ML R-TWT request or response frame can contain one or more ML TWT element(s) which carries the ML R-TWT information for one or more links.

The apparatus, method or system of any preceding implementation, wherein AP MLD can accept the ML R-TWT membership request on partial links of the ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein the membership negotiation of a ML R-TWT can occur before AP MLD announces the scheduling of that ML R-TWT.

The apparatus, method or system of any preceding implementation, wherein the ML TWT element can share the same element ID as TWT element.

The apparatus, method or system of any preceding implementation, wherein the ML TWT element can carry one link information field to indicate which links the information in all the Broadcast ML TWT Parameter Set Fields is applied to.

The apparatus, method or system of any preceding implementation, where each link information field can carry one link information field to indicate which links its information is applied to.

The apparatus, method or system of any preceding implementation, wherein said special MLD link comprises a non-simultaneous transmit receive (NSTR) link.

The apparatus, method or system of any preceding implementation, wherein said special MLD link comprises an enhanced multi-link single-radio (eMLSR) link.

The apparatus, method or system of any preceding implementation, wherein said special MLD link comprises an enhanced Multi-Link Multi-Radio (eMLMR) link.

As used herein, term "implementation" is intended to include, without limitation, embodiments, examples, or other forms of practicing the technology described herein.

As used herein, the singular terms "a," "an," and "the" may include plural referents unless the context clearly dictates otherwise. Reference to an object in the singular is not intended to mean "one and only one" unless explicitly so stated, but rather "one or more."

Phrasing constructs, such as "A, B and/or C", within the present disclosure describe where either A, B, or C can be present, or any combination of items A, B and C. Phrasing constructs indicating, such as "at least one of" followed by listing a group of elements, indicates that at least one of these group elements is present, which includes any possible combination of the listed elements as applicable.

References in this disclosure referring to "an embodiment", "at least one embodiment" or similar embodiment wording indicates that a particular feature, structure, or characteristic described in connection with a described embodiment is included in at least one embodiment of the present disclosure. Thus, these various embodiment phrases are not necessarily all referring to the same embodiment, or to a specific embodiment which differs from all the other embodiments being described. The embodiment phrasing should be construed to mean that the particular features, structures, or characteristics of a given embodiment may be combined in any suitable manner in one or more embodiments of the disclosed apparatus, system or method.

As used herein, the term "set" refers to a collection of one or more objects. Thus, for example, a set of objects can include a single object or multiple objects.

Relational terms such as first and second, top and bottom, upper and lower, left and right, and the like may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions.

The terms "comprises," "comprising," "has", "having," "includes", "including," "contains", "containing" or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises, has, includes, contains a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. An element proceeded by "comprises . . . a", "has . . . a", "includes . . . a", "contains . . . a" does not, without more constraints, preclude

the existence of additional identical elements in the process, method, article, or apparatus that comprises, has, includes, contains the element.

As used herein, the terms "approximately", "approximate", "substantially", "essentially", and "about", or any other version thereof, are used to describe and account for small variations. When used in conjunction with an event or circumstance, the terms can refer to instances in which the event or circumstance occurs precisely as well as instances in which the event or circumstance occurs to a close approximation. When used in conjunction with a numerical value, the terms can refer to a range of variation of less than or equal to ±10% of that numerical value, such as less than or equal to ±5%, less than or equal to ±4%, less than or equal to ±3%, less than or equal to ±2%, less than or equal to ±1%, less than or equal to ±0.5%, less than or equal to ±0.1%, or less than or equal to ±0.05%. For example, "substantially" aligned can refer to a range of angular variation of less than or equal to ±10°, such as less than or equal to ±5°, less than or equal to ±4°, less than or equal to ±3°, less than or equal to ±2°, less than or equal to ±1°, less than or equal to ±0.5°, less than or equal to ±0.1°, or less than or equal to ±0.05°.

Additionally, amounts, ratios, and other numerical values may sometimes be presented herein in a range format. It is to be understood that such range format is used for convenience and brevity and should be understood flexibly to include numerical values explicitly specified as limits of a range, but also to include all individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly specified. For example, a ratio in the range of about 1 to about 200 should be understood to include the explicitly recited limits of about 1 and about 200, but also to include individual ratios such as about 2, about 3, and about 4, and sub-ranges such as about 10 to about 50, about 20 to about 100, and so forth.

The term "coupled" as used herein is defined as connected, although not necessarily directly and not necessarily mechanically. A device or structure that is "configured" in a certain way is configured in at least that way, but may also be configured in ways that are not listed.

Benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential features or elements of the technology describes herein or any or all the claims.

In addition, in the foregoing disclosure various features may be grouped together in various embodiments for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Inventive subject matter can lie in less than all features of a single disclosed embodiment.

The abstract of the disclosure is provided to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

It will be appreciated that the practice of some jurisdictions may require deletion of one or more portions of the disclosure after that application is filed. Accordingly, the reader should consult the application as filed for the original content of the disclosure. Any deletion of content of the disclosure should not be construed as a disclaimer, forfeiture or dedication to the public of any subject matter of the application as originally filed.

The following claims are hereby incorporated into the disclosure, with each claim standing on its own as a separately claimed subject matter.

Although the description herein contains many details, these should not be construed as limiting the scope of the disclosure but as merely providing illustrations of some of the presently preferred embodiments. Therefore, it will be appreciated that the scope of the disclosure fully encompasses other embodiments which may become obvious to those skilled in the art.

All structural and functional equivalents to the elements of the disclosed embodiments that are known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the present claims. Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed as a "means plus function" element unless the element is expressly recited using the phrase "means for". No claim element herein is to be construed as a "step plus function" element unless the element is expressly recited using the phrase "step for".

What is claimed is:

1. An apparatus for wireless communication in a network, the apparatus comprising:

(a) a wireless communication circuit, as a wireless station (STA) which is a separate STA or as a STA in a multiple-link device (MLD), and operating as either a regular STA or an Access Point (AP) STA, for wirelessly communicating with other wireless stations (STAs) using a carrier sense multiple access/collision avoidance (CSMA/CA) mechanism on a wireless local area network (WLAN) in which enhanced distributed channel access (EDCA) is utilized for random channel access on all the links;

(b) a processor coupled to said wireless communication circuit for operating on the WLAN;

(c) a non-transitory memory storing instructions executable by the processor for communicating with other STAs; and

(d) wherein said instructions, when executed by the processor, perform steps of a wireless communications protocol for said wireless communication circuit, comprising:

(i) scheduling a multi-link (ML) restricted target wait time (R-TWT), by an AP station whose service periods (SPs) are scheduled on multiple links;

(ii) receiving a ML R-TWT request frame from a non-AP multiple-link device (MLD) to negotiate its membership of the ML R-TWT;

(iii) responding to said ML R-TWT request frame by an MLD of said AP with a ML R-TWT response frame to indicate acceptance or rejection of the ML R-TWT request frame request from the non-AP MLD; and

(iv) wherein the non-AP MLD becomes a member of the ML R-TWT if the AP MLD accepts its request.

2. The apparatus as recited in claim **1**, wherein the AP MLD can announce the scheduling of the ML R-TWT in a beacon frame, a (ML) probe response frame, (re)association frame, or ML R-TWT scheduling announcement frame.

3. The apparatus as recited in claim **1**, wherein an AP affiliated with the AP MLD can announce the scheduling of the ML R-TWT SPs on its own link only.

4. The apparatus as recited in claim **1**, wherein an AP affiliated with the AP MLD can announce the scheduling of all the ML R-TWT scheduled by the AP MLD.

5. The apparatus as recited in claim 1, wherein an AP affiliated with the AP MLD can only announce the scheduling of the ML R-TWTs of which some of the SPs are scheduled on the same link of the AP.

6. The apparatus as recited in claim 1, wherein an AP affiliated with the AP MLD can announce the scheduling of the ML R-TWTs and SL R-TWTs in a same frame.

7. The apparatus as recited in claim 1, wherein a ML R-TWT can consist of one or more SL R-TWTs which are scheduled by the APs affiliated with the AP MLD on different links.

8. The apparatus as recited in claim 1, wherein the AP MLD can assign a unique ML level R-TWT ID to the ML R-TWT to identify the ML R-TWT.

9. The apparatus as recited in claim 1, wherein the AP MLD can assign a same SL level R-TWT ID to the SL R-TWTs of the ML R-TWT to indicate that those SL R-TWTs belong to a same ML R-TWT.

10. The apparatus as recited in claim 1, wherein the SL R-TWTs with a same SL level R-TWT ID in a same ML TWT element can be regarded as a ML R-TWT.

11. The apparatus as recited in claim 1, wherein the SL R-TWTs with the same SP scheduling, e.g., same SP start time, SP duration, and SP interval, on different links can be regarded as a ML R-TWT.

12. The apparatus as recited in claim 1, wherein the SL R-TWTs with a same ML level R-TWT ID can be regarded as a ML R-TWT.

13. The apparatus as recited in claim 1, wherein ML R-TWT request or response frame can contain the link information to indicate the links where the corresponding ML R-TWT parameters are applied to.

14. The apparatus as recited in claim 1, wherein ML R-TWT request or response frame can contain one or more ML TWT element(s) which carries the ML R-TWT information for one or more links.

15. The apparatus as recited in claim 1, wherein AP MLD can accept the ML R-TWT membership request on partial links of the ML R-TWT.

16. The apparatus as recited in claim 1, wherein the membership negotiation of a ML R-TWT can occur before AP MLD announces the scheduling of that ML R-TWT.

17. An apparatus for wireless communication in a network, the apparatus comprising:

(a) a wireless communication circuit, as a wireless station (STA) which is a separate STA or as a STA in a multiple-link device (MLD), and operating as either a regular STA or an Access Point (AP) STA, for wirelessly communicating with other wireless stations (STAs) using a carrier sense multiple access/collision avoidance (CSMA/CA) mechanism on a wireless local area network (WLAN) in which enhanced distributed channel access (EDCA) is utilized for random channel access on all the links;

(b) a processor coupled to said wireless communication circuit for operating on the WLAN;

(c) a non-transitory memory storing instructions executable by the processor for communicating with other STAs; and

(d) wherein said instructions, when executed by the processor, perform steps of a wireless communications protocol for said wireless communication circuit, comprising:

(i) sending a frame containing multi-link (ML) target wait time (TWT) element for ML restricted-TWT (R-TWT) signaling by a non-AP STA;

(ii) wherein the ML TWT element carries one or more Broadcast ML TWT Parameter Set Fields; and

(iii) wherein the ML TWT element contains link information to indicate which links the information in the Broadcast ML TWT Parameter Set Fields is applied to as the R-TWT schedule is only scheduled on those links.

18. The apparatus as recited in claim 17, wherein the ML TWT element can share the same element ID as TWT element.

19. The apparatus as recited in claim 17, wherein the ML TWT element can carry one link information field to indicate which links the information in all the Broadcast ML TWT Parameter Set Fields is applied to.

20. The apparatus as recited in claim 17, wherein each link information field can carry one link information field to indicate which links its information is applied to.

21. An apparatus for wireless communication in a network, the apparatus comprising:

(a) a wireless communication circuit, as a wireless station (STA) which is a separate STA or as a STA in a multiple-link device (MLD), and operating as either a regular STA or an Access Point (AP) STA, for wirelessly communicating with other wireless stations (STAs) using a carrier sense multiple access/collision avoidance (CSMA/CA) mechanism on a wireless local area network (WLAN) in which enhanced distributed channel access (EDCA) is utilized for random channel access on all the links;

(b) a processor coupled to said wireless communication circuit for operating on the WLAN;

(c) a non-transitory memory storing instructions executable by the processor for communicating with other STAs; and

(d) wherein said instructions, when executed by the processor, perform steps of a wireless communications protocol for said wireless communication circuit, comprising:

(i) setting up a multi-link (ML) restricted target wait time (R-TWT), by an AP station whose service periods (SPs) are scheduled on multiple links, and for which a non-AP multiple-link device (MLD) may negotiate membership in the ML R-TWT;

(ii) scheduling a communication over a special MLD link of a first station on a first MLD; and

(iii) requiring that the second station of that first MLD must end its transmit opportunity (TXOP), leaving a given delay period, before the start of the first station on that MLD exchanging frames over the special MLD link.

22. The apparatus of claim 21, wherein said special MLD link comprises a non-simultaneous transmit receive (NSTR) link.

23. The apparatus of claim 21, wherein said special MLD link comprises an enhanced multi-link single-radio (eMLSR) link.

24. The apparatus of claim 21, wherein said special MLD link comprises an enhanced Multi-Link Multi-Radio (eMLMR) link.

* * * * *